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MAINTENANCE OF WATERFRONT FACILITIES

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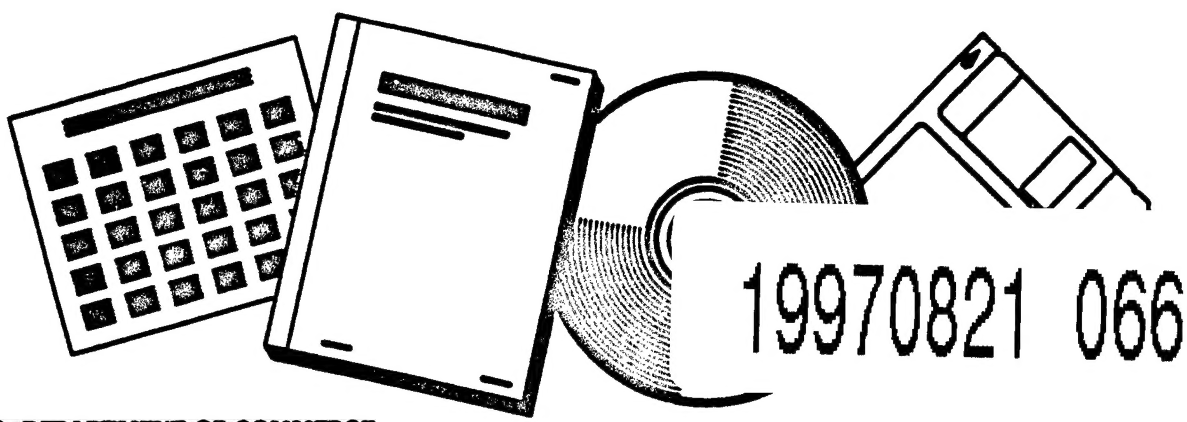

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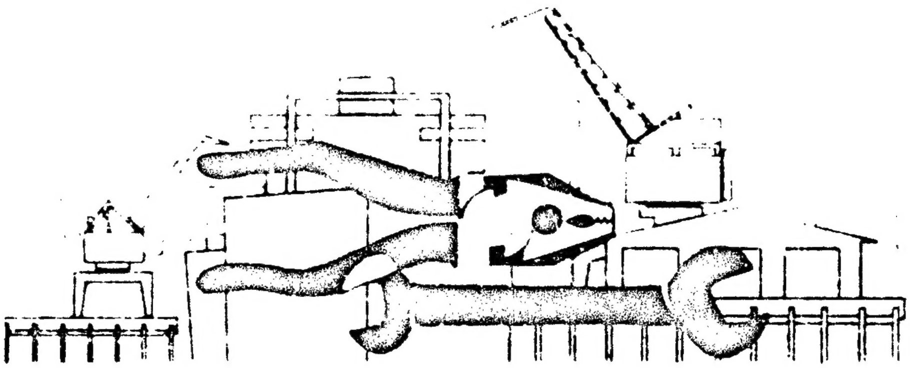

Maintenance of Waterfront Facilities

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Abstract: This manual is a guide for engineers, planners and maintenance supervisors in scheduling inspection, maintenance, and repair of waterfront structures and related facilities. Introductory chapters provide a summary of types of facilities, descriptions of materials, preventive maintenance planning, overview of types of facilities, descriptions of materials, preventive maintenance measures, and guidelines for safety. Inspection levels, methods, planning, and techniques and checklists are covered for above water and underwater inspection. Typical repair methods and techniques are described and illustrated for timber, concrete, steel, and rubble-mound structures.

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DEPARTMENTS OF THE ARMY,
THE NAVY, AND THE AIR FORCE
Washington, D.C.

FOREWORD

This manual provides guidance for the inspection, maintenance, and repair of waterfront structures and related facilities. Specifications and standards are listed to assist the planners in selecting the appropriate materials and preventive maintenance procedures. Inspection levels, methods, planning factors, and procedures are presented for both above water and underwater structures. The repair procedures discussed cover preventive measures, partial replacement, and total replacement concepts for timber, concrete, steel and rubble-mound structures. Each procedure is developed to guide the planners in the selection of the repair technique, inspection of field work for acceptability, and planning the follow-on inspection requirements.

The standards and methods presented are intended to accomplish the inspection, maintenance, and repair of waterfront structures and related facilities in the most efficient and cost effective manner. The procedures outlined have been developed from the best technical sources available in industry and the military services.

Recommendations for modifying or improving this manual should be submitted, through channels, to the appropriate military department.

By order of the Secretaries of the Army, the Air Force, and the Navy

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ABSTRACT

This manual is a guide for engineers, planners and maintenance supervisors in scheduling inspection, maintenance, and repair of waterfront structures and related facilities. Introductory chapters provide a summary of responsibilities and policies, elements of maintenance planning, overview of types of facilities, descriptions of materials, preventive maintenance measures, and guidelines for safety. Inspection levels, methods, planning, and techniques and checklists are covered for above water and underwater inspection. Typical repair methods and techniques are described and illustrated for timber, concrete, steel, and rubble-mound structures.

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CHAPTER 1. INTRODUCTION

1.1 GENERAL

1.1.1 Purpose. This manual is a guide for the inspection, maintenance, and repair of waterfront structures and related facilities. It is a source of reference for planning, estimating, and technical accomplishment of maintenance and repair work, and may serve as a training manual for facilities maintenance personnel.

1.1.2 Scope. This manual provides guidance for typical maintenance and repair of waterfront facilities to retain them in continuous readiness for use by the Fleet and in support of military marine operations. The scope of maintenance and repairs accomplished shall be governed by present and planned future use of the facilities, their anticipated life, and the cost of repair versus complete rebuilding or replacement.

The manual is organized to cover:

MAINTENANCE PLANNING AND TYPES OF FACILITIES (Chapters 1 and 2)

- Joint service responsibilities, maintenance policies, and the basic elements of maintenance planning.

- Overview of typical waterfront facilities.

MATERIALS AND PREVENTIVE MAINTENANCE (Chapter 3)

- Description of materials at the waterfront and the types of deterioration likely to be encountered.

- Preventive maintenance measures for each type of material.

SAFETY (Chapter 4)

- Guidelines for personnel and work site safety.

INSPECTION (Chapter 5)

- Overview of inspection levels, methods, planning, equipment and documentation.

- Guidance and checklists for above and underwater inspection of timber, concrete, steel, and rubble mound structures.

REPAIR (Chapters 6, 7, 8, 9, and 10)

- Descriptions and illustrations of repair methods and techniques for the more typical probiems encountered.

- Guidance for material selection along with pertinent references and standards.

The inspection chapter will guide the engineer, planner, and inspector in organizing, coordinating, and performing the inspection. Individual inspection objectives, illustrations, and checklists are provided as stand-alone documents for easy identification and reproduction.

The repair chapters are similarly organized to guide engineering and maintenance personnel in planning, organizing, and coordinating the repairs to waterfront facilities. Each repair procedure is a stand-alone document, with the repair description on the left and the illustration on the right hand page. In chapters 6, 7 and 8, repair procedures are numbered; example: TR-1 (timber repair number one), to permit identification and reference. For many of the repair scenarios, problem definition and application constraints are also provided to guide the user in selecting the repair technique to match the problem to be corrected.

1.1.3 Cooperation and Coordination

1.1.3.1 Intraservice Functions. Cooperation and coordination of waterfront maintenance activities among the installation departments concerned should be continuous. Properly planned and executed maintenance programs prevent undesirable interruption of operations on military installations. Supply officers, through normal channels, provide standard items of materials and equipment for waterfront maintenance.

1.1.3.2 Interservice and Interdepartmental Functions. Cooperation and coordination in conducting waterfront maintenance are encouraged at all levels of command. Appropriate liaison should be established and maintained between major commands and installations in a geographical area. Cross-service assistance should be provided as necessary in the interests of economy and maximum utilization of manpower and equipment. Technology transfer of improved maintenance methods and materials should be continuously encouraged.

1.2 JOINT SERVICE RESPONSIBILITY. The responsibility for inspection, maintenance, and repair of waterfront structures and related facilities rests with each service. Because of the quantity of waterfront facilities in inventory, the Navy retains a strong technology base in design, construction, and maintenance of waterfront structures, such as piers, wharves, quaywalls, drydocks, dolphin assemblies, and moorings; the Army maintains a similar capability for coastal harbor facilities, such as breakwaters, jetties, groins, and seawalls.

1.2.1 Army. Staff, command, and technical responsibility for maintenance and repair of waterfront structures at Army installations will conform to assignments set forth in AR 420-10 (reference 1).

U.S. Army Engineer divisions and districts provide specialized expertise in evaluation of coastal erosion, and design and maintenance of coastal and harbor facilities.

Requests for assistance should be forwarded through channels to the Director of Facilities Engineering, DAEN-FEZ, Office, Chief of Engineers, Forrestal Building, Washington, DC 20314.

1.2.2 Navy. The Naval Facilities Engineering Command (NAVFAC), Engineering Field Divisions (EFD), station public works departments, and Navy Public Works Centers are responsible for organizing and performing waterfront inspection, maintenance, repair, and minor construction programs to support the Commanding Officer at each naval shore installation. NAVFAC MO-322 (reference 2) contains guidelines for shore facilities inspection and preventive maintenance programs.

NAVFAC EFDs provide special design and maintenance/repair management expertise to assist the shore activities in carrying out their mission of maintaining waterfront facilities. This includes, in addition to standard steel and concrete waterfront structures knowledge, special expertise and responsibilities for wood preservation and treatments.

Requests for assistance should be forwarded through channels to the appropriate NAVFAC Geographical EFD in accordance with current Navy directives.

1.2.3 Air Force. Policy and standards for the maintenance, repair, and minor construction of waterfront structures are set forth in Air Force Manuals 85-1 and 86-1 (references 3 and 4).

Design and assistance for maintenance and repair are available at each Major Command. Each Major Command will:

- Ensure that effective preventive and corrective maintenance measures are established and accomplished at all installations under its jurisdiction.

- Provide qualified technical supervision for personnel engaged in these operations.

- Provide for training of personnel engaged in maintenance.

- Make certain that base civil engineer personnel engaged in direct field supervision of maintenance operations, or those who function independently of direct supervision, are technically competent and thoroughly familiar with the performance of all phases of this activity, as outlined in this publication.

1.3 MAINTENANCE STANDARDS, POLICIES, AND CRITERIA

1.3.1 Standards. The standards and criteria contained in this manual have been developed by the Army, Navy, and Air Force with the concurrence and approval of the Assistant Secretary of Defense. Compliance with these standards is mandatory in order that the maintenance of waterfront facilities at military installations will be uniform, will adequately support the operational missions of the installations, and will permit interservice assistance and support, where possible, in the interest of efficiency and economy.

1.3.2 Engineering. The need for and accomplishment of major repairs and rehabilitation of existing waterfront facilities will be based on experience, judgment, and engineering evaluation. When waterfront structures are in an inactive status, the maintenance policies will be consistent with the anticipated future mission of the installation and in accordance with the inactivation plan. The services of qualified technical personnel will be used to

assist in the establishment of waterfront maintenance programs. A glossary of waterfront terms is provided in the back of this manual.

1.3.3 Related Published Material. Requirements for the design and construction of waterfront facilities are found in references 5 through 14. References 15 and 16 are manuals prepared by the American Association of Port Authorities on port design and construction and port maintenance, respectively. Reference 2 is especially important relative to inspection of waterfront structures. Reference to other published materials, which provide related or more extensive information on specific areas of waterfront maintenance, is made where appropriate throughout this manual.

1.4 MAINTENANCE PLANNING

1.4.1 Overall Programming and Economic Considerations. In maintenance planning and execution, full consideration must be given to future expected use of each facility, the life expectancy of the facility, and the life cycle cost of periodic repairs versus replacement of a facility or major components. The level of maintenance and programming of major repairs should be planned in consonance with the future requirement for the facility and planned replacement. The maintenance program shall be designed to include prevention of deterioration and damage, prompt detection of deficiencies, and early accomplishment of maintenance and repairs to prevent interruptions to operations or limiting full use of a facility.

The primary goal of the maintenance program is to prevent facility deficiencies from constraining the operating forces. A well planned and executed program will keep each facility at full efficiency and minimize downtime. The Navy's principal guide for maintenance management is NAVFAC MO-321 (reference 17).

1.4.2 Elements of the Maintenance Program.

1.4.2.1 Inspection. Continuous, rigorous inspections are necessary for an effective maintenance program. The use of guides, check-off forms, reports, and record systems is an integral part of inspection. Types of inspections typical to waterfront facilities are:

- Operator inspection consisting of examination, lubrication, and minor adjustment performed by operators on a continuous basis. For waterfront facilities, this includes inspection of pier utility systems during hook-up and disconnection of ships.

- Preventive maintenance inspection is the scheduled examination and minor repair of facilities and systems that do not have operators and would otherwise not be subject to inspection. Pier fender systems, fire protection systems, and under pier utilities are examples.

- Control inspection is the major scheduled examination of all components and systems on a periodic basis to determine and document the condition of the facility and to generate major work required.

It is recommended that inspections be made annually of all basic structures and more frequently for fenders, utilities, and movable equipment such as

brows and camels. Additional inspections will be necessary under certain circumstances, such as a tsunami, high tides, earthquakes, typhoons, and heavy freezes. Inspections may be made from the structures, from a boat or float, or below the water line by qualified divers. Engineering personnel should either perform the inspection or be onsite to provide guidance and field evaluation of procedures. Underwater television is often employed in visual inspections.

1.4.2.2 Maintenance. Maintenance is the recurrent day-to-day, periodic, or scheduled work that is required to preserve or restore a facility to such a condition that it can be effectively utilized for its designed purpose. It includes work undertaken to prevent damage to or deterioration of a facility that otherwise would be more costly to restore. The more common concerns in maintenance of waterfront facilities are:

- Painting and protective coating.
- Repair and replacement of fender components to prevent damage to ships and the pier.
- Repairs to prevent erosion by surf and wave action.
- Maintenance of utility systems to prevent outages.
- Protection of piling in the intertidal zone (ITZ).
- Patching and repair of concrete spalls and cracks.

1.4.2.3 Repair and Reconstruction. Repair is the restoration of a facility to such a condition that it can be effectively utilized for its designed purpose. The repair is accomplished by overhaul, reprocessing, or replacement of constituent parts or materials that have deteriorated by action of the elements or usage and have not been corrected through maintenance. Repair can be incorporated in a concurrent modernization program. The more common repair projects for waterfront facilities are:

- Replacement/reconstruction of fender systems.
- Repair of eroded or failing seawalls and quaywalls.
- Repair and resurfacing of pier decks.

1.4.2.4 Control of Destructive Marine Organisms. This control begins with the use of materials resistant to marine organisms when waterfront structures and other harbor facilities are designed and constructed. The control is a continuing requirement involving the taking of all known corrective measures and providing effective countermeasures to inhibit the growth of destructive organisms in waterfront facilities.

CHAPTER 2. TYPES OF WATERFRONT FACILITIES

The types of waterfront facilities discussed in this chapter include:

- Berthing facilities for mooring and providing support to ships and craft.

- Drydocks used for construction of ships and to expose the underwater portion of the ship for repair, modification, inspection, or maintenance.

- Coastal protection structures designed to protect shorelines or harbors.

- Components of waterfront structures such as fender systems, piling, dolphins, utility distribution systems, deck and mooring hardware, and fleet moorings.

2.1 BERTHING FACILITIES. The basic facilities to provide berthing support for ships and craft are piers and wharves. These facilities provide a safe space for ships to moor and receive shore utilities and other hotel services, to load and unload cargo and personnel, to transfer ordnance, to receive fuel, and to perform ship maintenance, repair, and fitting-out. Berthing facilities are also provided for tugboats, small craft, barges, and harbor support equipment.

2.1.1 Piers. Piers are docks which extend outward from the shore into the water. Piers may be used for berthing on one or both sides of their length. There are basically four types of pier structures with distinct differences in configuration; open, closed, combination, and floating piers.

- **Open piers** are pile supported platform structures which allow water to flow underneath. Conventionally, open piers are single-deck structures, although recently a double-deck Navy pier was constructed at Charleston, SC. Figures 2-1 and 2-2 show schematics of a single and double-deck, open pier.

- **Closed piers,** or solid fill piers, are constructed so that water is prevented from flowing underneath. The solid fill pier is surrounded along the perimeter by a bulkhead to hold back fill. Figure 2-3 shows a schematic of a solid fill pier. A special type of solid fill pier is a mole pier. Mole piers are earthen structures that extend outward from the shore. The sides and offshore end of the pier are retained and protected by sheet pile, circular cells or walls of either masonry or concrete. Provided the water is an adequate depth, the pier is used to berth ships.

- **Floating piers** are constructed of steel or concrete and are connected to the shore with access ramps. Guide piles in the center of the pier, or a chain anchorage system, prevent lateral movement and allow the pier to move up and down with the tide. The floating pier may be a single-deck or a double-deck structure. A floating pier design concept developed by the Navy is shown in figure 2-4.

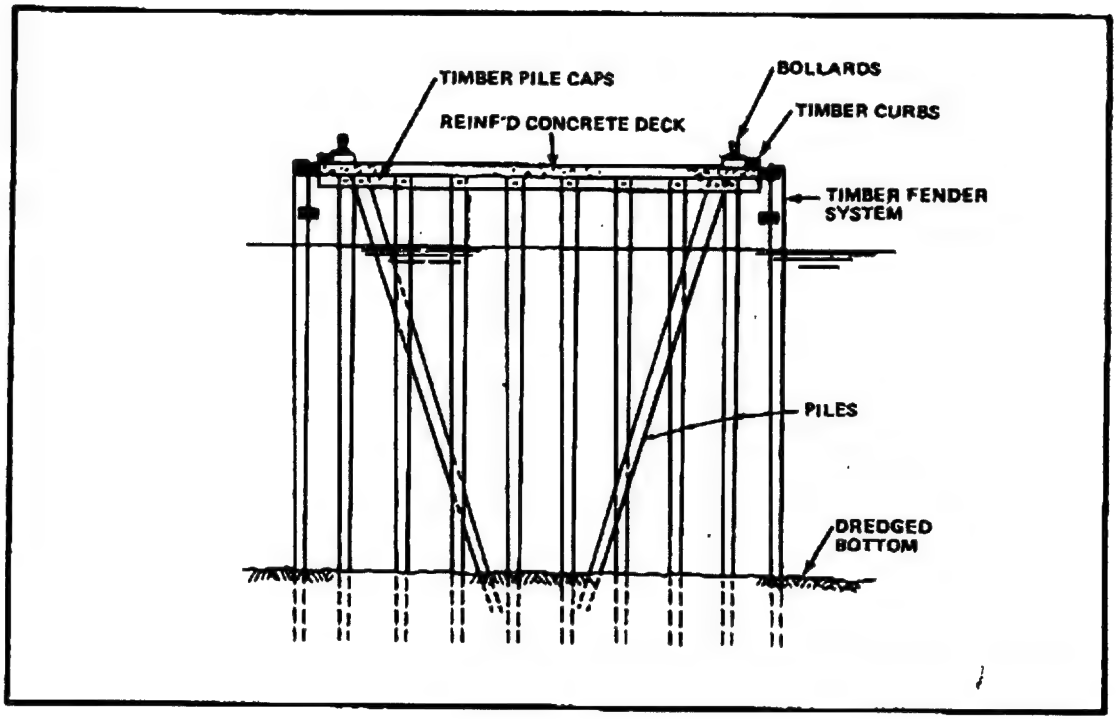


Figure 2-1. Single-deck, Open Pier.
(FIG 3-2 990; 3-3)

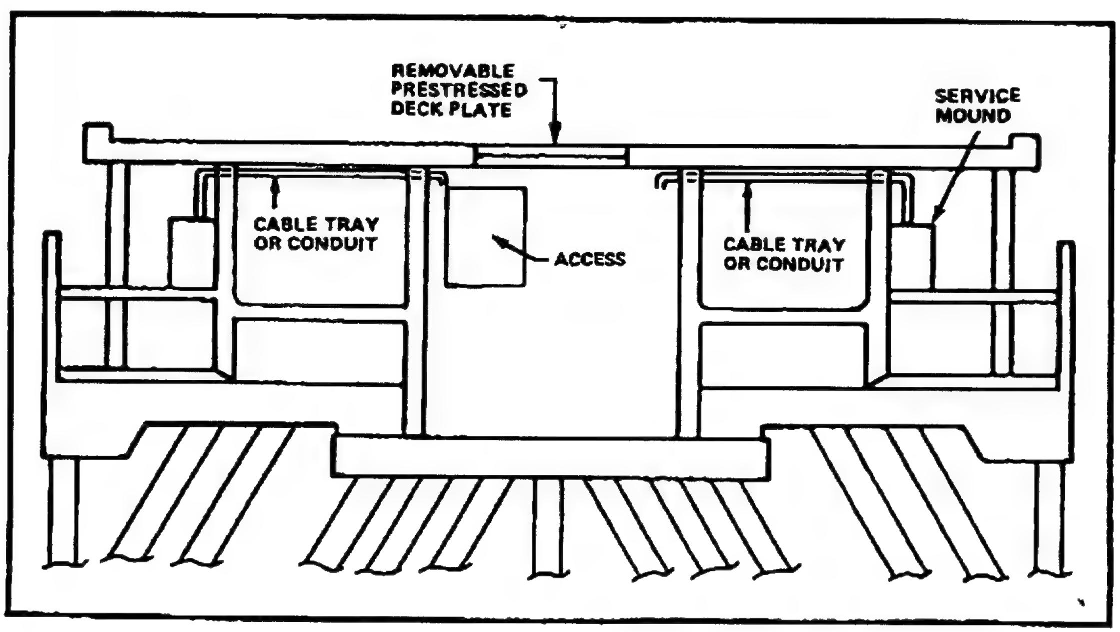


Figure 2-2. Double-deck, Open Pier.
(FIG 3-3 990, 3-4)

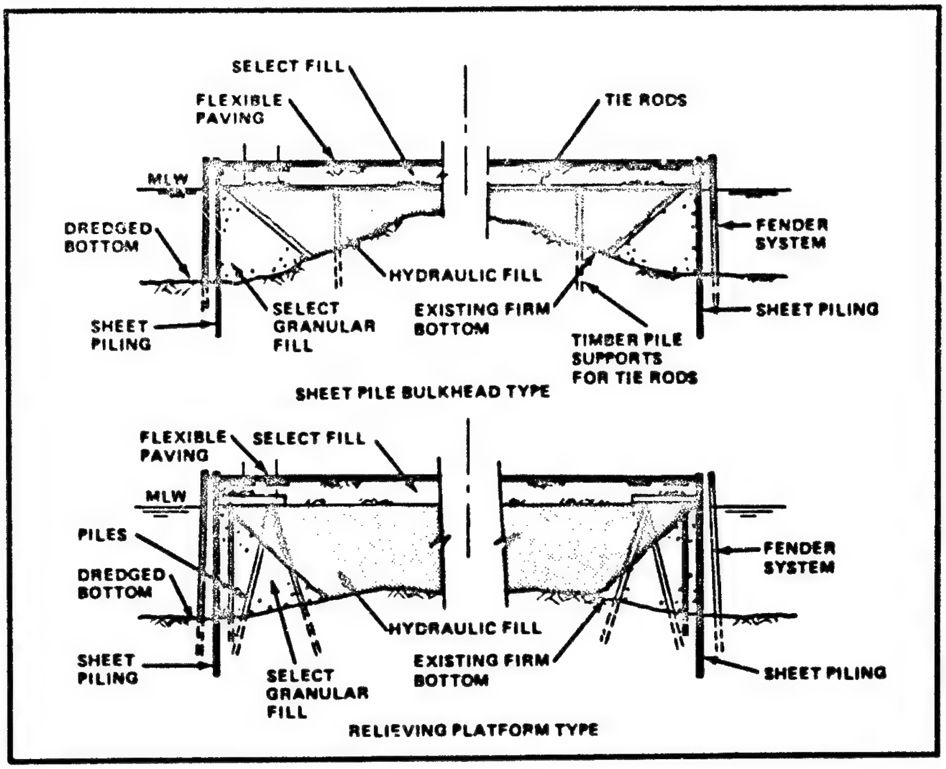


Figure 2-3. Solid Fill Pier.

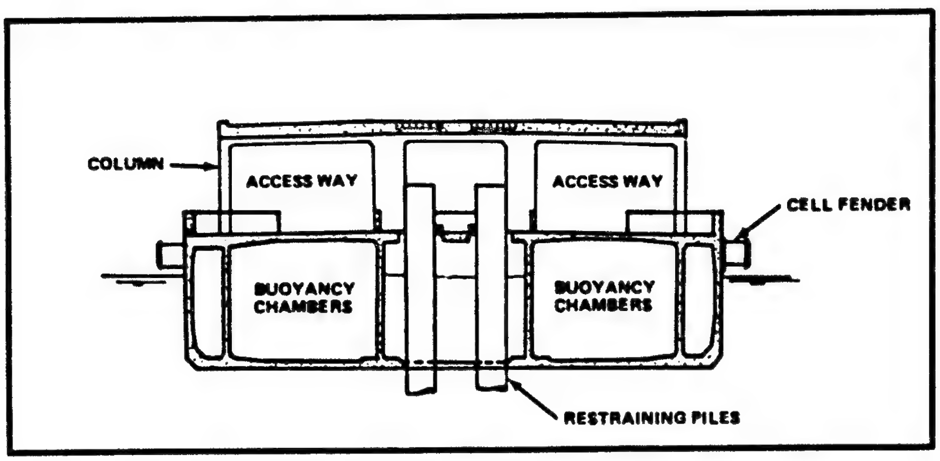


Figure 2-4. Floating Pier Design Concept.

A more detailed discussion of the design and configuration of piers is documented in NAVFAC Design Manual 25.01, Piers and Wharves (reference 5).

2.1.2 Wharves and Quaywalls. Wharves are docks which are orientated approximately parallel to the shore. They are normally connected to the shore along their full length, and a retaining structure is used to contain earth or stone placed behind the wharf. This retaining structure is often referred to as the quaywall or bulkhead. Ships are moored along the outshore face of the wharf. The typical wharf types are the same as the basic pier types and include open and closed (or solid fill) configurations. Figure 2-3 shows a solid-fill pier with a configuration similar to a closed wharf.

2.2 DRYDOCKING FACILITIES. Drydocking facilities are used for construction of ships and to expose the underwater portion of ships for repair, modification, inspection, or maintenance. Several different types of drydocks exist, including graving drydocks, floating drydocks, marine railways, and vertical syncrolifts.

- **Graving drydocks** are fixed basins adjacent to the water's edge and are constructed of stone masonry, concrete, or sheet pile cells. They can be closed off from the waterway by a movable watertight barrier (entrance caisson or flap gate). After closing the barrier, the basin is pumped dry which allows the ship to settle on blocking set on the dock floor. Figure 2-5 shows a schematic of a graving drydock.

- **Floating drydocks** are ship or U-shaped structures that are submerged by flooding to permit a vessel to enter and then pumped dry to raise the vessel out of the water.

- **Marine railways** consist of a ramp extending into the water, a mobile ship cradle on wheels or rollers, groundway ship cradle tracks, hoisting machinery, and chains or cables for hauling the ship cradle endwise or sidewise. Figure 2-5 shows a typical marine railway.

- **Syncrolifts** consist of platforms which are lowered into the water to receive ships. The ship is then lifted out of the water on the platform by electrical powered hoist equipment. Figure 2-5 shows a typical vertical syncrolift drydocking system.

More detailed discussions of drydocking facilities can be found in NAVFAC Design Manuals DM-29.01, Graving Drydocks; DM-29.02, Marine Railways; and DM-29.03, Drydocking Facilities Characteristics. Maintenance of drydocking facilities is not specifically covered in this manual.

2.3 COASTAL PROTECTION STRUCTURES. Structures designed to reduce the erosive effects of wave action, or to protect harbors from excessive wave action and the formation of sandbars, are classified as coastal protection structures. The common coastal protection structures are seawalls, groins, jetties, and breakwaters. NAVFAC DM-25.04, Seawalls, Bulkheads, and Quaywalls (reference 6), and NAVFAC DM-26.02, Coastal Protection (reference 10), provide additional information on the design and configuration of coastal protection structures.

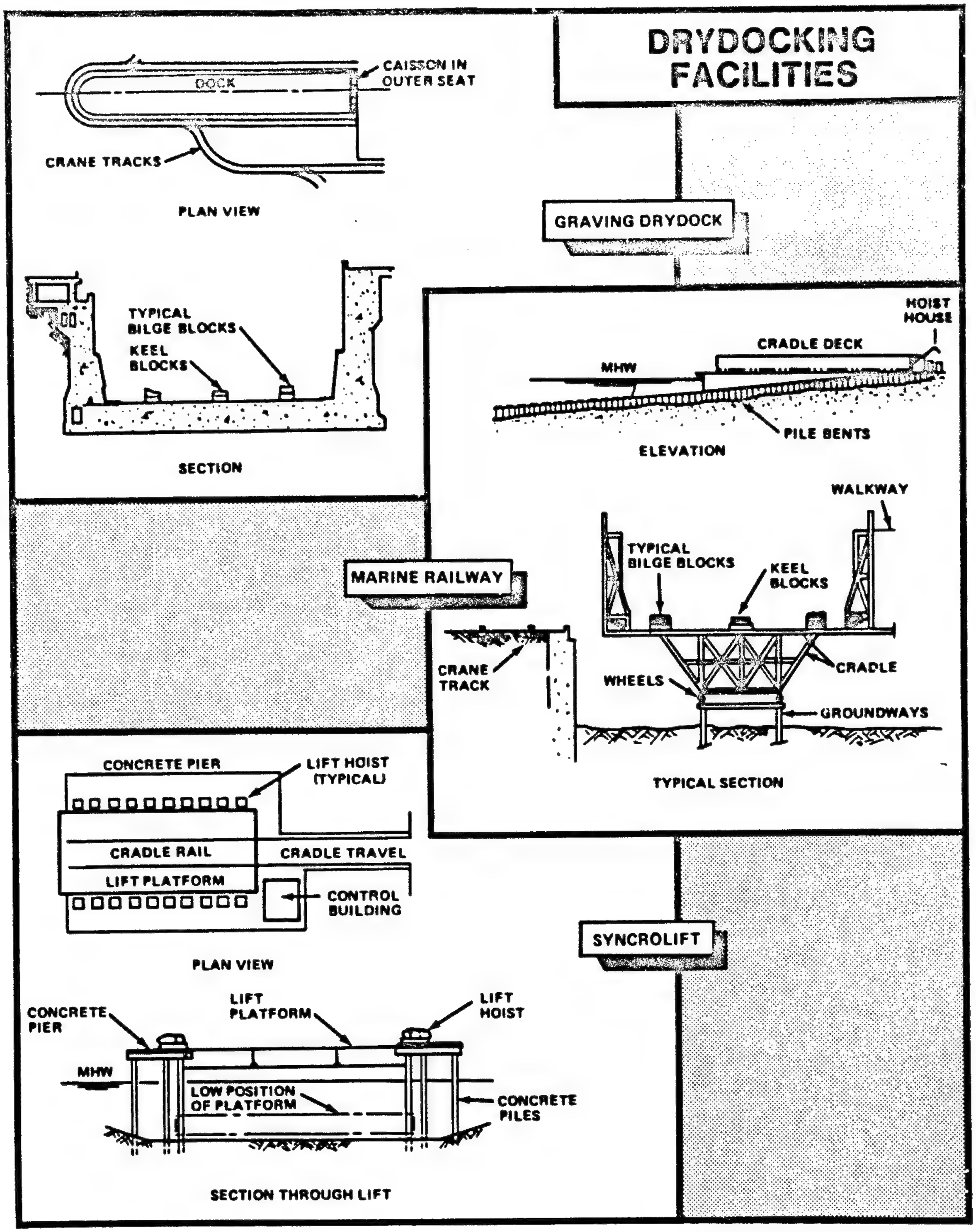


Figure 2-5. Drydocking Facilities.

2.3.1 Seawalls. Seawalls are massive coastal structures built along the shoreline to protect coastal areas from erosion caused by waves and flooding during heavy seas. Seawalls are constructed of a variety of materials including rubble-mounds, granite masonry, or reinforced concrete. They are usually supplemented by steel or concrete sheet pile driven into the soil and are strengthened by wales and brace-type piles. Figure 2-6 shows three seawall configurations.

2.3.2 Groins. Groins are structures designed to control the rate of shifting sand by influencing offshore currents and waves so that erosion of the shoreline is minimized. Groins project outward, perpendicular to the shoreline, and are constructed of large rocks, precast concrete units, reinforced or prestressed concrete piles, steel sheet piles, or timber cribbing filled with rock. Figure 2-7 shows an example of a groin.

2.3.3 Jetties. Jetties are structures which extend from the shore into deeper water to prevent the formation of sandbars and to direct and confine the flow of water due to currents and tides. These structures are normally located at the entrance to a harbor or a river estuary. Jetties are usually constructed of mounds of large rubble to a height several feet above the high tide mark. Figure 2-8 shows the position of jetties at a harbor entrance.

2.3.4 Breakwaters. Breakwaters are large rubble-mound structures located outside of a harbor, anchorage, or coastline to protect the inner waters and shoreline from the effects of heavy seas. These barriers help to ensure safe mooring, operating, loading, or unloading of ships within the harbor. Breakwaters may be connected to the shore or detached from the shore. There are three general types of breakwaters, depending upon the type of exposed face. The exposed face may be vertical, partly vertical and partly inclined, or inclined. Figure 2-9 shows a section of a typical breakwater.

2.4 COMPONENTS OF WATERFRONT STRUCTURES. Numerous components of basic facilities are present at the waterfront to aid in port operations. These components are integral parts of piers and wharves and include fender systems, piling, dolphins, deck and mooring hardware, and utility distribution systems, or they may be offshore systems vital to ship operations, such as fleet moorings.

2.4.1 Fender Systems. Fender systems are used on piers to protect the ship and the pier during berthing operations and while the ship is moored. The most widely used fender system consists of timber fender piles, timber wales, and chocks, with rubber compression fender units between the system and the pier to absorb berthing impacts. This type of system is the highest maintenance cost portion of the pier. The trend is toward utilization of longer lasting and more resilient fender systems.

The main types of fenders, and their components, that may be found installed in ports are:

a. Fender pile systems: timber, steel, or concrete piles.

b. Fenders fixed to the pier:

- Rubber-in-compression units: cylindrical, rectangular, trapezoidal, wing-type, and D-shaped units.

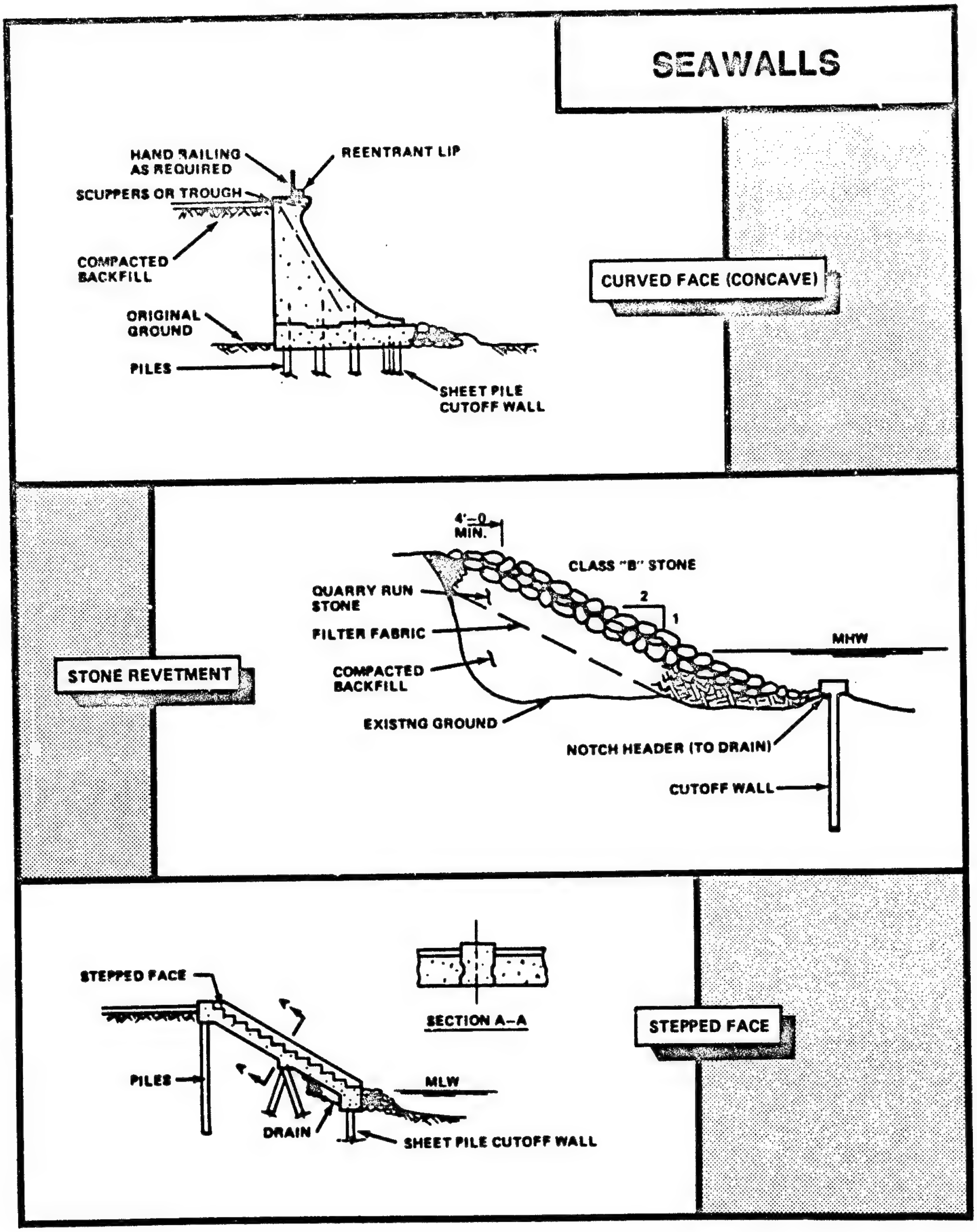


Figure 2-6. Seawall Configurations.

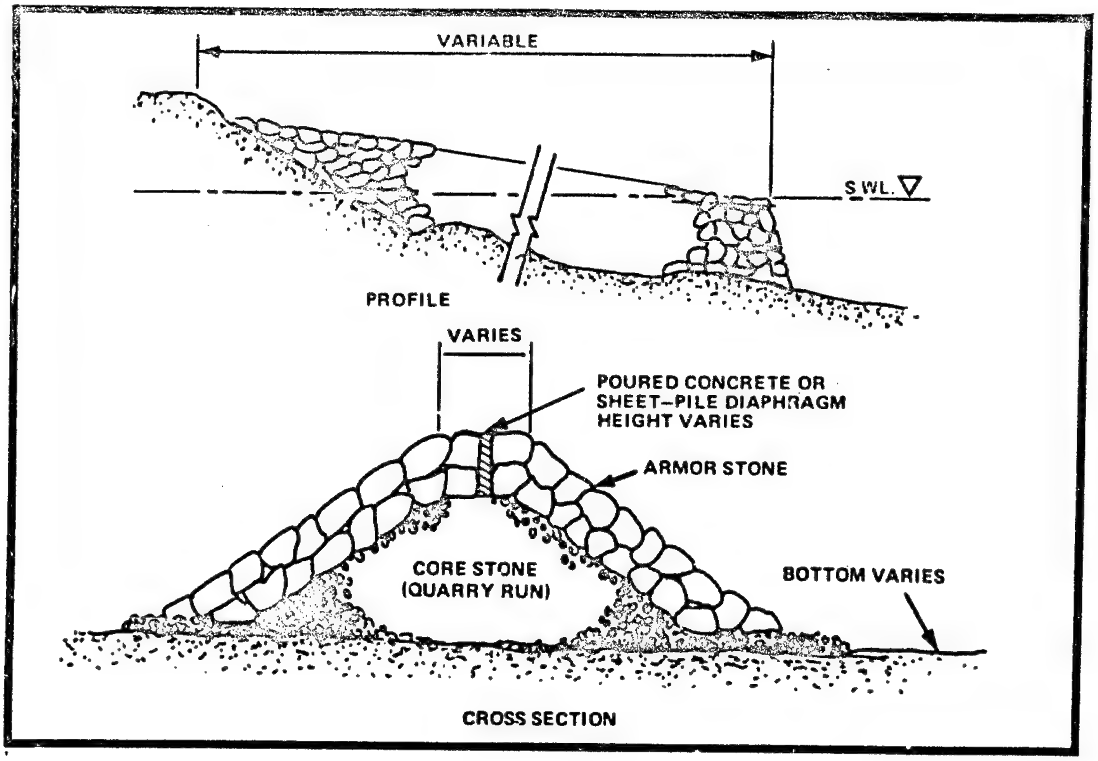


Figure 2-7. Groin.

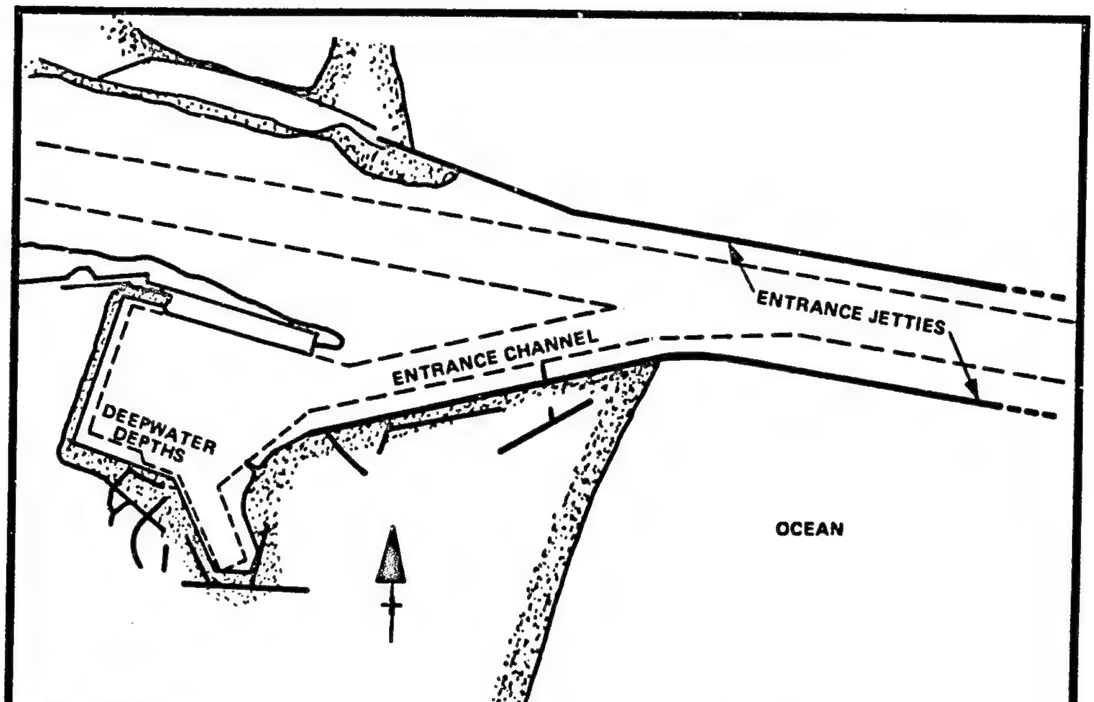


Figure 2-8. Typical Location of Jetties.

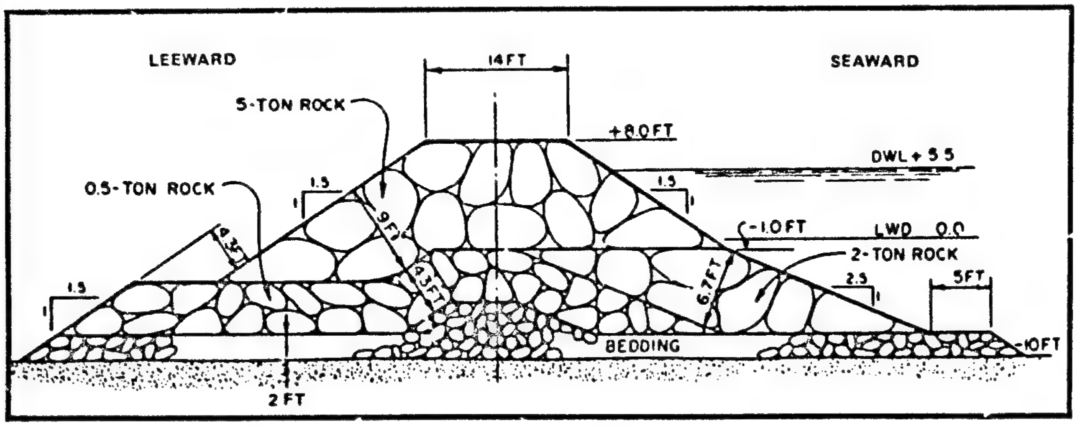


Figure 2-9. Typical Breakwater Section.

- Rubber-in-shear fenders: rectangular rubber column and Raykin fender.

- Buckling fender: buckling column fender and cylindrical cell fender.

c. Floating resilient fenders connected to or suspended from the pier: pneumatic fenders, and foam-filled fenders.

NAVFAC DM-25.01 (reference 5) gives more in-depth descriptions of types of fender systems. The maintenance of fender systems is covered in a supplement to this manual.

2.4.2 Piling. Piling is an integral part of all open piers and wharves. The exposure of piling makes it susceptible to severe environmental attack: corrosion, marine borer attack, and erosion. Piling is made from concrete, wood, or steel and frequently requires protective coatings, preservatives, or wraps to ensure a long life.

There are basically four types of piling; vertical bearing piles, batter piles, fender piles, and sheet piles. Bearing piles are used to support the weight of the pier and loads on the pier. Batter piles provide lateral and longitudinal stability. Fender piles are used to absorb the impact of berthing ships. Sheet piling is used for various waterfront structures to retain fill.

2.4.3 Dolphins. A dolphin is a group of piles placed near piers and wharves, or in turning basins and ship channels. These structures are used to guide vessels into their moorings, to mark underwater structures (shoals or shore), and to support navigational aids.

2.4.4 Fleet Mooring. A fleet mooring is an offshore anchoring system which consists of various hardware items: chain, cable, sinkers, anchors, and buoys. The offshore anchoring system is placed in a fixed location so that vessels, when entering the port, can anchor to the buoys. NAVFAC MO-124, Mooring Maintenance, provides details on the maintenance of fleet mooring systems, so they are not covered in this manual.

2.4.5 Deck and Mooring Hardware. Various deck and mooring hardware, such as gratings, handrails, bollards, bitts, cleats, chocks and rings, are utilized on piers and wharves. These items require inspection and maintenance to ensure personnel safety and adequate mooring facilities for ships.

2.4.6 Utility Distribution Systems. Utility distribution systems are provided on most piers and wharves to service the ships. Utilities available at most piers and wharves include: steam, potable water, saltwater, sewage and oily waste collection, compressed air, electricity, fuel, telephone service, and fire alarm systems. These utility systems require frequent maintenance of conduit, piping, valves, expansion joints, drains, regulators, and insulation. The maintenance of utility systems and their components is covered by various service manuals and commercial publications, and is not included in this manual.

CHAPTER 3. MATERIALS AND PREVENTIVE MAINTENANCE

Common structural materials used for construction and repair in waterfront areas are wood, concrete, steel, and plastic. Proper selection of materials and systems can greatly reduce maintenance costs and increase the life of facilities. Wood preservatives, coatings, special concrete mixtures, cathodic protection, and selection of alloys and synthetic materials are measures available to aid in extending the life of the materials and structures.

This chapter describes various types of materials used in construction and repair of waterfront facilities; types of deterioration, corrosion, and other problems that may be encountered with each material; and preventive maintenance (PM) measures that should be taken. Appendix A lists specifications and standards referenced in the text and others applicable to waterfront maintenance. Table 3-1 summarizes preventive maintenance actions that should be a part of all waterfront maintenance programs.

Some of the information in this chapter was extracted from the following references:

- Construction Materials for Coastal Structures, US Army, Corps of Engineers Coastal Engineering Research Center, Report No. SR-10, Moffatt and Nichol, Engineers, February 1983 (reference 18).

- Survey of Techniques for Underwater Maintenance/Repair of Waterfront Structures, Revision No 1, Naval Civil Engineering Laboratory, Childs Engineering Corporation, December 1985 (reference 19).

- Painting of Facilities, A Training Manual, Air Force Engineering and Services Center, Naval Civil Engineering Laboratory, September 1983 (reference 20).

3.1 WOOD AND TIMBER. Wood and timber members are widely used for the construction and maintenance of waterfront facilities due to availability, economy, and ease of handling relative to other construction materials.

The common forms of wood products used include dimension lumber, piles and poles, beams and stringers, and glued and laminated timbers. The primary applications at the waterfront include:

- Older piers, wharves, bulkheads, and quaywalls constructed from dimension lumber, beams and stringers, and round timber piles.

- Fender systems constructed from beams and stringers and round timber piles.

- Pile dolphins constructed from round timber piles.

- Floats and camels constructed from logs, beams and stringers, dimension lumber, glued and laminated wood, and miscellaneous forms.

- Groins constructed from beams and stringers and round timber piles.

Table 3-1. Summary of Preventive Maintenance Actions.

Preventive Maintenance Action	Paragraph
Wood and Timber - General:	
Use pressure treated members in repair/replacement.	3.1.2.1
Maintain paint and other coatings in good condition.	3.1.2.2
Treat exposed areas: cuts, bolt holes, pile cutoffs.	3.1.2.3
Timber Piles:	
Consider installing:	
- Plastic wrapping or jacket.	3.1.2.4
- Anti-fungus cartridges embedded in pile top.	3.1.2.4
- Pile top bonnet and preservative.	3.1.2.4
Concrete - General:	
Design and constructions actions:	See Chapter 7
- Use higher strength mix.	
- Use Type II or V cement.	3.2.1.1
- Provide adequate cover over reinforcing steel.	3.2.2
- Use joints to control cracking.	
- Ensure complete curing to reduce cracking.	
Maintain surface coatings in good condition.	3.2.5.1
Fill cracks.	3.2.5.2
Concrete Piles:	
Install wood jacketing.	3.2.5.3
Steel - General:	
Design actions:	
- Select type of steel for environmental conditions of use.	3.3.1
- Substitute corrosion resistant metals for steel	3.4
- Increase thickness to allow for corrosion over life cycle.	
- Minimize use of dissimilar metals.	3.4.5
Maintain protective coating in good condition.	3.3.3.1
Minimize galvanic corrosion:	3.4.5
- Insulate dissimilar metals from each other.	
- Use protective coatings.	
- Keep cathodic area small relative to active metal.	
Provide cathodic protection system.	3.3.3.2

Maintenance of wooden structures involves the replacement of decayed or damaged wood and the application of a preservative or coating. If repairs are to be reduced in the future, exposed wood used in the splash zone and pile caps must be treated with an effective preservative or coating system to retain its strength and longevity against severe weathering, effects of saltwater, and destructive fungi, marine organisms, insects, and bacteria attack.

The common types of lumber used in the United States are Douglas fir, southern pine, spruce, hemlock, redwood, cedar, and other pine species such as lodgepole, ponderosa, and white. Primarily, Douglas fir is used on the West Coast and southern pine is used on the East Coast due to availability. Round timber piles are made from Douglas fir or southern pine according to availability and size requirements for piling. These piles should conform to the DoD adopted specification, American Society for Testing and Materials (ASTM) D 25, and the guidelines in NAVFAC Guide Specification NFGS-02361. The various other types of lumber should conform to standards set by the American Lumber Standards Committee (ALSC) and should be properly graded and marked before acceptance.

3.1.1 Wood Deterioration. Biological and physical deterioration of wood can bring about rapid destruction of waterfront facilities. Improper design and construction procedures which can lead to biological deterioration include: (1) inadequate preservative treatment, (2) improper handling of treated wood, (3) a design which promotes retention of water, and (4) a design that unnecessarily places wood timbers below water. Major design deficiencies which promote physical deterioration include: (1) insufficient strength of piles which results in overloading (loss of strength and embrittlement caused by treatment with salts and other preservatives is an important design consideration), (2) improper connection hardware or pile connections which restrict load transfer to other parts of the structure, and (3) inability of sheet pile walls to retain backfill or insufficient strength in the soil foundation which results in sheet pile movement.

3.1.1.1 Biological Deterioration. Wood-destroying organisms infest wood structures both above and below the waterline. Marine borers are the principle cause of deterioration in the immersed zones and are found in harbors and estuaries worldwide. Insects and fungi are the main wood-destroying organisms above the waterline. (See references 21 and 22).

a. **Marine Borers.** There are two general types of marine borers that attack marine timbers; crustaceans and molluscs. The major wood-boring crustaceans are the Limnorians; the principle wood-destroying molluscs are the Teredines (Teredo and Bankia) and the Pholads (Martesia). See figure 3-1.

Of the three common crustacean wood borers Limnoria, Sphaeroma, and Chelura - only Limnoria is considered to be economically important. These borers burrow just below the wood surface forming a network of interlacing tunnels. The weakened wood is easily eroded by wave action often resulting in a characteristic "hourglass" shape. Limnoria tripunctata is of particular importance because it can attack creosoted wood.

The Teredines are commonly referred to as "shipworms" because of their wormlike appearance. Penetration of the wood occurs during the microscopic larval stage. As the shipworms grow, their tunnels increase in diameter and length while the entrance holes remain about the same size. Attacked piles may appear sound on the surface, yet be completely riddled.

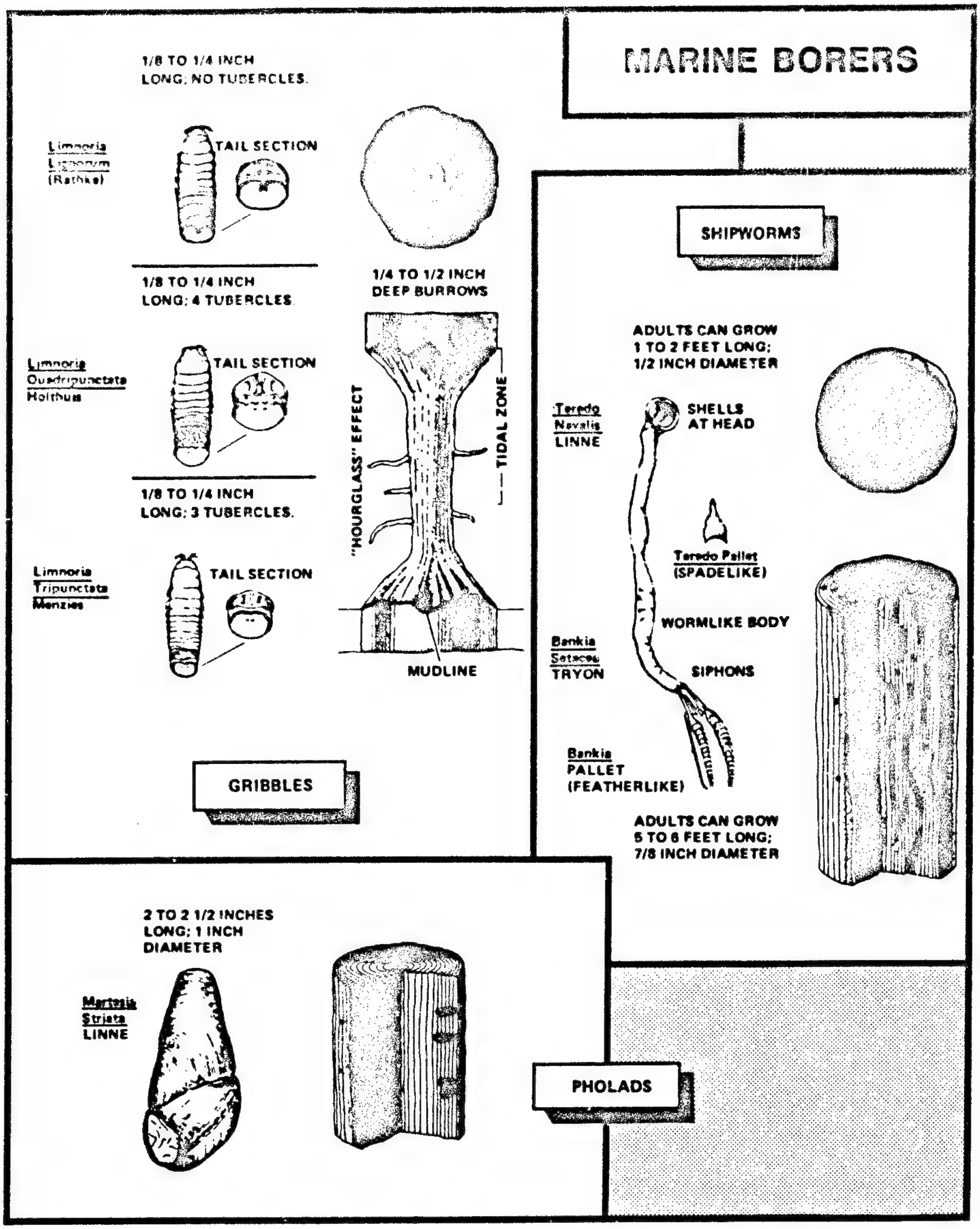


Figure 3-1. The Three Groups of Marine Borers (After reference 23).

Pholads bore into wood, soft rock, or concrete for protection. These clam-like organisms have pear-shaped shells which can reach 2-1/2 inches in length. Like the Teredines, Martesia can cause considerable structural damage to wood, but both of these molluscs can be more effectively controlled by creosote preservative treatment than the Limnorians.

b. **Insects.** Termites are the most destructive wood-destroying insects found on waterfront structures. Other insect pests of importance include wood-boring beetles, ants, and bees. An insect frequently associated with damage to piers and docks is the wharf-borer, <u>Nacerda</u>, a beetle 1/4 to 1/3 inches long with a yellowish-brown to dark red color. Some insects, such as termites, require wood for food and shelter; others, such as carpenter ants, require wood for nesting only. Most wood-destroying insects thrive under damp conditions.

c. **Fungi.** Three categories of wood-decay fungi are: white rot, which tends to bleach the affected wood; brown rot, often termed "dry rot", which produces a brown, crumbling type of decay; and soft rot, which leads to a softening of the wood. Slight strength reduction of infected wood can be caused by stain fungi which produce bluish black to steel gray or brownish discoloration of the wood. Molds also produce a discoloration of the wood surface and are regarded as merely a blemish, but their presence indicates that conditions may be favorable for decay organisms. Most wood-destroying fungi require damp conditions for growth.

3.1.1.2 Physical Deterioration. Physical deterioration of timber piles and other wood structures is generally due to the following causes:

a. **Abrasion.** Abrasion of timber piles occurs principally in the intertidal zone. The rate at which piles are destroyed by abrasion depends upon the amount of floating debris in the harbor, the velocity of water moving past the piles, ice in the harbor, and the action of marine borers. Fender piles are also abraded by camels and ships.

b. **Overload.** Overloading of piles may result from a continuous heavy load or infrequent, severe loads. Overloading may be caused by vertical and horizontal loads. Failure of one pile requires the adjacent piling to carry the extra load. Continual overloading can lead to collapse of the entire structure.

c. **Connection Failure.** When a timber pile connection fails, the structure is free to move and will eventually fail. If untreated wood is exposed, connection failure may first allow the entry of marine borers if below the waterline, or insects and fungi if above the waterline.

d. **Timber Wall Movement.** Outward wall movement can result from horizontal loading of the backfill material caused by excessive loading behind the structure or failure of tie-backs. Loss of backfill material can result in movement in the opposite direction. If either condition is allowed to continue, failure of the structure will result.

e. **Ice Lift.** Single timber piles or those used in light structures may be lifted by ice freezing to the pile and pulling it as the ice moves with the tide.

3.1.2 Preventive Maintenance for Wood and Timber. The primary PM measure at the waterfront is to select the type of wood best suited for the particular use and to purchase wood products and timber piles which have been treated with quality preservatives and methods. The most important field PM are those actions to preserve wood and timber with paint and other coatings. Field techniques should be used to eliminate or minimize cuts and holes made in the members at the site, particularly those made below water. If cuts and holes are made, special field PM preservative treatment is required. In addition, there are other PM measures applicable to timber piles using encasements and retardants. Specifications and standards applicable to the preservation of wood are listed in appendix A. Preventive maintenance measures discussed in this section are summarized in table 3-1.

3.1.2.1 Pressure Treatment. Pressure treatment of the outer sapwood of timbers with preservatives is the most important and effective method of protecting wood. It permits deeper and more uniform penetration of preservative, and closer control of retention levels. The preservative penetrates the wood from 0.5 inches to 4.0 inches, depending on the type of wood, and provides protection from fungi, marine borers, insects and bacteria. The American Wood Preservers Bureau (AWPB), the American Wood Preservers Association (AWPA), and Federal Specification TT-W-571 govern the treatment processes that must be performed on wood used in waterfront areas. In the field, pile cutoffs, framing cuts, and holes that expose untreated wood to the environment are treated as discussed in paragraph 3.1.2.3.

The choice of preservative treatment depends on how and where the wood is to be used. Wood preservatives are classified in three categories: creosote preservatives, oil-borne preservatives, and water-borne preservatives.

Creosote preservative and creosote solutions are the most commonly used preservatives at the waterfront because they are not easily leached from the wood and are not corrosive to metals. Creosote and creosote-coal tar solutions, both derived from bituminous coal, can be used for immersed wood. Creosote is commonly diluted with petroleum oil for treatment of wood not subject to immersion. An important disadvantage of creosoted piling, however, is the fact that it is readily attacked by the marine borer, Limnoria tripunctata. Also, creosote and creosote solutions cannot be used where it may come in contact with people.

Oil-borne preservatives are dissolved in a petroleum solvent and include pentachlorophenol, copper naphthenate, tributyl tin oxide, and copper-8-quinolinolate. Oil-borne preservatives are suitable for wood members out of the water for protection against insects and fungi. Treated wood can be painted, does not swell and distort, is easily handled, and will not corrode metal. Before the solvent evaporates, it is more flammable than untreated wood. Pentachlorophenol is the most effective of these preservatives but is also highly toxic.

Water-borne preservatives are toxic metallic salts dissolved in water for easier application. The most common water-borne preservative is chromated copper arsenate (CCA). Wood pressure treated with CCA or ammoniacal copper

arsenate (ACA) can be used either above or below the waterline. Either of these salts in combination with creosote (dual treatment) is more effective in preventing marine borer damage than any single treatment. Other water-borne preservatives for use above the waterline include chromated zinc chloride, fluor-chrome-arsenate-phenol, and acid copper chromate.

All preservative treatments have drawbacks that should be considered. Metallic salts, for example, will seriously embrittle wood. More importantly, these toxic chemicals present environmental and personnel safety problems. Proper safety, installation, and disposal procedures should be carefully followed.

3.1.2.2 Coatings for Wood. Wooden structures continuously immersed in seawater or subject to immersion during tidal changes are not usually painted except for marking identification or location. In general, coating of wood is confined to structures such as buildings located in waterfront areas to protect the wood from weathering and for appearance.

a. **Surface Preparation.** All necessary repairs such as cutting, nailing, and caulking should be made to timbers before the surface is prepared for painting. Any grease or oil must first be removed by solvent cleaning as described in Steel Structures Painting Council Surface Preparation-1 (SSPC SP-1) for steel surfaces. This can best be accomplished using rags soaked with mineral spirits. After solvent cleaning, the wood is manually or power sanded to remove splinters, dirt, old loose paint, and other contaminants that may deter tight bonding of paint. Any residual dust from sanding should be removed by brushing or blowing with clean, dry air.

b. **Recommended Coatings.** The specifications referenced in this paragraph are listed in appendix A. Due to ongoing changes in regulations covering paint solvents, the user needs to keep abreast of the regulations and select the paints which meet the environmental requirements for paint solvents. **Alkyd coatings** are usually used when the wood is to be sealed from water penetration. One prime coat (MIL-P-28582) and two topcoats (TT-E-490 or TT-P-102) are recommended. This system can also be used for spot repairs to damaged coatings. Either of the alkyd topcoats or a coat of acrylic latex (TT-P-19) paint can be used if a topcoat for appearance is desired. Alkyd paints can be applied by brush, roller or spray (conventional or airless), but brushing of the prime coat is recommended for greatest penetration of the wood surface. Each coat should dry overnight before topcoating.

Acrylic latex coatings are usually used on wood that is not to be sealed but allowed to "breath"; that is, moisture vapor may penetrate through the coating. Three coats (TT-P-19) should be applied directly on the wood by brush, roller, or spray. Brushing the first coat will result in greatest penetration and coverage of the wood. Topcoats can be applied as soon as the earlier coat is dry to the touch. If the wood is extremely dry, spray a fine mist of water on the surface before applying the first coat. An appearance topcoat and repairs to damaged coatings are also made with an acrylic latex coating.

3.1.2.3 Treating Exposed Areas of Wood. Cut surfaces of wood members, pile cutoffs, bolt holes, and any other exposed surfaces of treated wood members must be treated in the field. Cut surfaces and pile cutoffs should be treated

in accordance with AWPA Standard M4. Pile cutoffs should then be painted with coal tar pitch. Holes for bolts and plugs in piles and timbers should be treated with the same type of wood preservative used for the member. Bolt holes should be treated under pressure with a mechanical bolt hole treater, if available, or thoroughly doused to saturation.

3.1.2.4 Protection of Timber Piles. All timber piling in the marine environment, including piling properly treated, are eventually attacked by wood destroying organisms. Pilings are also commonly subject to icelift and abrasion. As a result, protection with plastic wraps is often required, in addition to preservative treatment, in order to minimize the impact of these environmental factors.

The use of plastic wrapping to protect piling against marine borer damage, at and below the waterline, does offer considerable economic benefit by effectively eliminating borer damage, reducing future repair costs. The polyvinyl chloride (PVC) and polyethylene wrapping smothers borers already in the wood and prevents the entry of more borers. Installation of barrier wraps are described in repair technique TR-3 contained in Chapter 6. Fender piles prewrapped with a thick, heat-shrink polyethylene are provided with a slippery surface that prevents exposure of untreated wood due to wear from camels. An example of a molded polyethylene jacket used for ice protection is shown in figure 3-2.

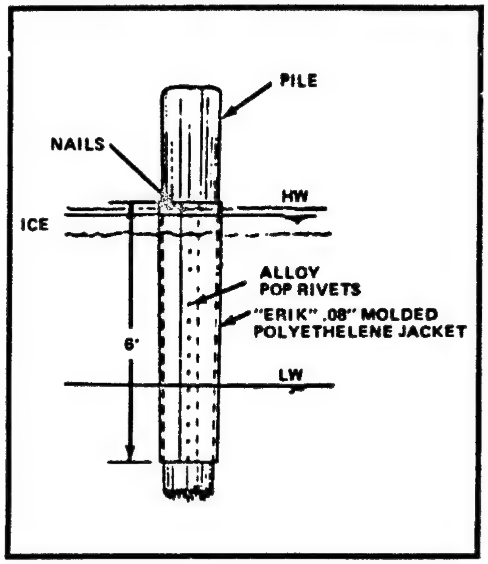


Figure 3-2. Timber Pile Jacket.

Timber pile tops, cut off after the pile is driven, expose the pile to rapid decay, even when the pile has been treated. Research and testing by Oregon State University on Douglas fir piles has shown that current prevalent methods of protecting cutoff piles are not adequate without a well maintained water-shedding cap combined with preservatives. Waterborne preservatives FCAP and ammonium bifluoride (ABF) were found to be the most effective. ABF, in semipermeable bags attached to the pile, releases hydrogen fluoride gas that kills fungi in the wood. Cutoff pile tops should be treated immediately with a preservative and protected with a cap, such as coal tar cement.

Two methods are available to protect timber pile tops by using encasements and retardants (reference 19). They include:

a. **Anti-Fungus Cartridges.** Commercial cartridges are available that can be embedded in the cut top of timber piles and will slowly leach into the pile to retard and prevent rot. Holes are bored in the top of the pile, cartridges inserted, and the holes plugged with hardwood. This method is useful where the pile top is accessible and subject to wetting by rain or spray. See figure 3-3.

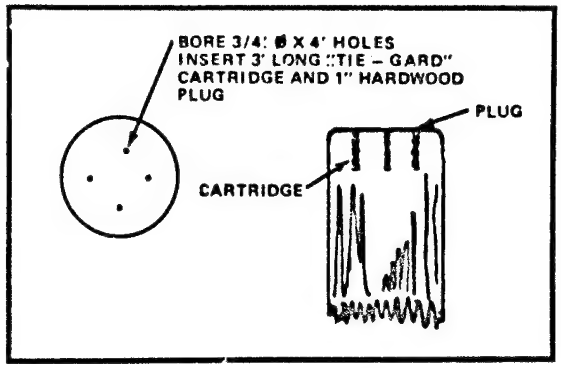


Figure 3-3. Anti-Fungus Cartridges for Timber Piles.

b. **Pile Top Bonnet.** This method uses a reservoir of liquid preservative in the pile top and a protective bonnet fabricated of metal or fiberglass. The preservative must be one that meets environmental protection regulations. This method can be used to repair a rotted pile head, as shown in figure 3-4, or as a preventive measure on a sound pile.

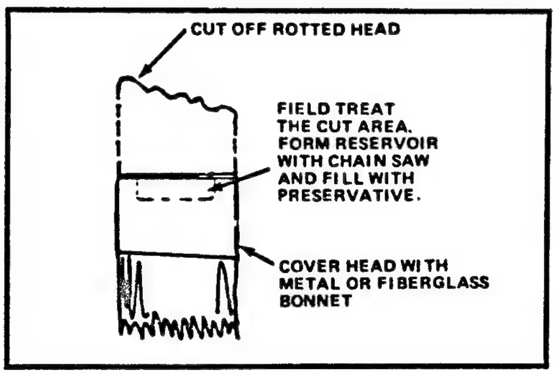


Figure 3-4. Pile Top Bonnet for Timber Piles.

3.2 CONCRETE. Concrete is the predominant construction material for waterfront facilities due to its durability, strength, and economy as a bulk construction material. Steel and wood do not have the bulk properties and adaptability of concrete. In addition, basic components to make concrete are readily available at most locations. Applications of concrete at the waterfront include:

- Seawalls, bulkheads, and revetments utilize concrete as the dominant material of construction. It is used as the facing material to absorb wave impact, retain fill, and reduce the erosive effects of wave action. Concrete is used in piles, curved-faces, sheet piling, and other forms.

- Piers, wharves, and quaywalls utilize concrete as the dominant material. All the elements of pier construction such as piles, dock units, girders, substructures, or bulkheads are constructed of concrete. Concrete is also used to protect wood or steel from corrosion, weathering, fungal decay, or marine organism attack.

- Groins are built from concrete sheet piles and panels. The piles or panels are usually prestressed units and are tied in place with a concrete cap.

- Breakwaters utilize various shapes of precast concrete. These concrete shapes are used as armor units for rubble structures.

- Submerged structures utilize concrete which is cast in place underwater or precast and used to support piles, infall and outfall structures, and underwater pipelines.

- Floating structures utilize concrete for pontoons, quays, wharves, piers, and facilities for small boats.

Deterioration of concrete near or in seawater can be due to improper mix and curing, excessive impacts and loads, severe weathering, chemical attack, and volume changes. Concrete available today is developed to resist deterioration and retain its durability over a long lifetime.

Concrete in waterfront facilities must meet the criteria set by the American Concrete Institute (ACI) Standard 318. This standard covers the building code requirements for concrete with and without reinforcing. Additional design information, with emphasis on waterfront facilities, is included in NAVFAC DM-25.06 (reference 7) and DM-2.04 (reference 24). These manuals provide general design and application data for a variety of waterfront structures. NAVFAC Guide Specifications NFGS-02363 and NFGS-02367 provide guidelines on concrete piling.

3.2.1 Components of Concrete. Concrete is a mixture of portland cement, coarse and fine aggregate, and water. Various admixtures, polymers, reinforcements, and coatings can be used to improve the properties, workability, and service life of concrete. Preparation and proportioning of concrete mixtures should follow the recommendations of the Portland Cement Association's, Principles of Quality Concrete, and ACI 211, Recommended Practice for Selecting Proportions for Concrete.

3.2.1.1 Cement. Five types of portland cement are described in ASTM C 150. For **concrete structures exposed to seawater, Types II and V** should be used. Type II is a sulfate-resisting cement and can be used if the concrete is not subject to freezing and thawing conditions. It is more readily available than Type V. Type V is a more durable cement for waterfront applications than Type II because of its higher resistance to sulfate attack. Other cement products are available, such as low alkali cements for use with potentially reactive aggregates.

Proprietary products that will set-up rapidly (in 5 to 15 minutes) are not recommended for use because of the calcium chloride they use as an accelerator.

3.2.1.2 Aggregates. Aggregates are used in concrete mixtures to improve strength and reduce costs. They usually make up 60 to 80 percent of the volume of the concrete. The shape and size of the aggregate should meet the requirements for normal aggregates specified in ASTM C 33. Common aggregates are sand, gravel, crushed rock, or mixtures of these. The use of **marine** aggregate such as coral, should be **avoided.** If marine aggregate is the only available material, it must be washed thoroughly with fresh water to remove the salt.

In some applications, special aggregates may be used to make lightweight concrete for floating and suspended structures. Most lightweight concretes have a density between 80 and 110 pounds per cubic foot compared to 150 pounds per cubic foot for normal weight concrete. Lightweight aggregate concrete is durable in the marine environment. The common aggregates for lightweight concrete are expanded shale or clay, tuff, pumic, and scoria. Lightweight concrete can also be produced by omitting the fine aggregates in the mixture or by producing highly aerated concrete.

3.2.1.3 Water. Water quantity and quality will affect the durability, strength properties, and workability of concrete. In practice, water should be of drinking quality. The ratio of water to cement has a direct effect on the strength of the concrete and its permeability. A **maximum water-to-cement ratio of 0.40 by weight** is crucial for concrete used in a marine environment. Seawater should never be used for making concrete, because it dramatically increases the corrosion of reinforcing steel.

3.2.1.4 Admixtures. Chemical admixtures are used to give specific properties to the concrete to improve durability, finishability, or workability. If admixtures are required, they should meet the appropriate ASTM or ACI specifications. Admixtures which improve freeze-thaw resistance or reduce water requirements are recommended for waterfront concrete.

Water-reducing admixtures are available to allow a reduction in the water-to-cement ratio. Pozzolan minerals and silica fume aid in reducing the permeability. Normal range water reducers and superplasticizers are admixtures which permit the reduction of the water-to-cement ratio.

Air-entraining admixtures are available to improve the concrete's ability to resist freeze-thaw conditions. Air-entraining agents should be used to incorporate from 5 to 7 percent of entrained air into the concrete. ASTM C 260 covers the air-entraining agents. Air-entraining agents also improve workability of the concrete.

Accelerator admixtures are available for tasks which require rapid setting products. These increase the early strength of concrete but have little effect on the final strength. Accelerators containing excessive chloride should not be used since they increase corrosion of reinforcing steel.

3.2.2 Reinforcing Steel. Reinforcing steel for concrete in waterfront facilities is the same as for conventional concrete structures and should conform to ASTM A 615, A 616 or A 617. A cover of 2 to 3 inches of concrete over the

steel will maximize durability. Where corrosion of reinforcing steel has been a problem, epoxy coated reinforcing bars conforming to ASTM A 775 should be used. Epoxy coated bars should be used for repairs when existing bars are replaced. When reinforcing bars are exposed during repairs but are not replaced, they should be coated using an epoxy paint such as MIL-P-24441. Do not use epoxy coated rebar, however, in areas subject to high impact.

3.2.3 Special Types of Concrete Mixtures. Special concrete mixtures include polymer concrete, polymer-portland cement concrete, and fiber reinforced concrete. These special concrete mixtures can be useful in patching and repairing concrete, and may provide improvements over conventional concrete mixtures when used and applied correctly.

Polymer concrete does not contain portland cement. Epoxy concrete is one common type of polymer concrete which is readily available and possesses excellent bond and tensile strength qualities.

Fiber reinforcements improve the tensile strength, toughness, and ductility of concrete. Concrete containing fibers of steel, glass, or polypropylene may be used in repair of concrete. Though the steel fibers will corrode near the surface, the alkaline environment of the cement paste will protect steel fibers in the interior. In general, however, steel fibers should not be used in the marine environment. Glass and polypropylene fibers avoid the corrosion problem of steel fibers, but their usage is still under development.

3.2.4 Causes of Concrete Deterioration. Cracking and spalling of concrete are the results of corrosion. Generally, corrosion occurs as salt, water, carbon dioxide, and oxygen diffuse to the steel. The resulting products of corrosion occupy a greater volume than the steel, causing internal pressures that eventually exceed the concrete's low tensile strength.

3.2.4.1 Chemical Attack. The most common chemical attack is from sulphates in seawater which cause a softening of the surface of concrete. The softened surface is then worn down by wave action. Other causes of chemical attack (alkali-aggregate reaction) are poor quality aggregates reacting with alkali in the cement. Alkali-aggregate reaction expands the aggregate and results in cracking. This results in chemical decomposition of the cement in the concrete.

3.2.4.2 Corrosion of Reinforcing Steel. The high alkalinity of cement paste protects steel from corrosion. With sufficient time, carbonation reduces the alkali film around the steel. Carbonation causes an increase in permeability. Corrosion will then occur if oxygen is present. In the splash zone, the wet and dry cycles provide conditions for the chloride and oxygen to corrode the steel. Accordingly, steel corrosion in concrete is found primarily above water, while steel in submerged concrete shows corrosion less frequently.

When steel corrodes, the rust product increases in volume many times over its original volume. Expansion of the rust causes cracking of the concrete. These cracks run parallel to the reinforcement. Eventually, concrete covering the reinforcing steel spalls off.

3.2.4.3 Cracking of Concrete. As concrete dries it shrinks, which in turn, can cause cracks when drying is too fast. The concrete can also crack later as

the internal water is lost and the concrete cannot contract freely. Temperature changes can also cause cracking. Freezing water in and around concrete piles can lead to two types of deterioration, cracking and spalling. The first is freezing of water inside the pile causing longitudinal cracks. The other type of freezing, involving water getting into cracks and fissures on the outside of the pile and causing the concrete to spall away, is more common. If the rate of concrete failure is rapid, the corroded reinforcing bar may remain although the concrete is completely deteriorated. Shrinkage cracking can be minimized by proper curing and using a minimum amount of water in the mix design. Temperature cracking can be controlled in concrete by using expansion joints and temperature reinforcement.

Overload conditions, particularly during construction, can cause cracks. Waterfront structures are subject to soil settlement conditions. When settlement is uneven, cracks usually result.

Prevention and control of cracking may be improved by proper design of the concrete structure and measures taken during construction. The measures which must be taken during repair of concrete structures are discussed in chapter 7.

3.2.5 Preventive Maintenance for Concrete. Most of the measures to prevent deterioration of concrete must be taken during design of the concrete mix, design of the structure, and construction. Proper design for concrete is contained in ACI standards and service design manuals.

The main objectives of preventive maintenance are to:

- Keep water out of the concrete.
- Protect the reinforcing steel.
- Prevent and control cracking.
- Prevent chemical actions.

The primary PM measures that should be continually taken are surface coatings for concrete and treatment of cracks.

3.2.5.1 Surface Coatings for Concrete. Concrete structures that are periodically or continuously immersed in seawater or subject to seawater splash are seldom painted except for marking identification or location. One exception involves piles being coated in the intertidal zone to reduce the effect of the freeze-thaw cycle. Buildings or other waterfront structures that do not come into direct contact with seawater, may be coated to seal the surface from water penetration, provide protection from surface weathering, or provide a pleasing appearance.

a. **Surface Preparation.** Patching, caulking, and other repairs must be made to concrete structures before the surface is prepared for coating. Any

efflorescence or laitance (white to gray powdery deposits from the concrete interior) is first removed with a clean, dry wire or stiff bristle brush. The surface is then scrubbed with a 5 to 10 percent solution of muriatic (hydrochloric) acid, rinsed with fresh water, and allowed to dry. Any grease or oil is then removed by solvent cleaning as described in SSPC SP-1. This can usually best be accomplished by using rags soaked with mineral spirits. Then, the concrete is carefully waterblasted or sandblasted to remove dirt and old coatings. Coatings in good condition and adhering freely to the surface may be allowed to remain, if they are compatible with the coating system to be applied; that is, if they are of the same generic type. Any residual dust from blasting must be removed by brushing or blowing with clean, dry air before application of coatings.

b. **Recommended Coatings.** The standard specifications for coatings recommended in this paragraph are listed in appendix A. If the concrete is to be sealed against moisture penetration, two coats of **chlorinated rubber** (TT-P-95, Type 1) or **epoxy polyamide** (MIL-P-24441) are recommended. The epoxy polyamide will chalk freely in direct sunlight. If this is undesirable, a topcoat of **aliphatic polyurethane** (MIL-C-83286) should be used to resist exterior weathering. If the concrete surface has slight irregularities, such as fine cracks that are unsightly, a **textured coating** (TT-C-555) may relieve the problem while sealing the surface. It is applied in one or two coats over a compatible primer to give a total of about 20 mils dry film thickness.

If the concrete is not to be sealed, but an appearance finish is desired, two coats of **acrylic latex** paint (TT-P-19) are recommended.

All of these coatings, except the textured coating, are easily applied by brush, roller, or spray. Brushing of the first coat onto the concrete will result in better penetration and coverage. The textured coating may require special spray equipment or other special procedures, so the manufacturer's instructions should be followed carefully. The manufacturer's recommended primer should also be used to ensure compatibility with substrate and textured coating. Latex acrylic paint (TT-P-19) should be applied as a topcoat to weathered textured coating when a more pleasing appearance is desired.

3.2.5.2 Treatment of Cracks. Sealing and caulking of cracks that require no cutting or extraordinary routing is considered a part of preventive maintenance. More complex crack repair is discussed in chapter 7.

The very small cracks will be filled or spanned by surface coatings discussed in paragraph 3.2.5.1. Medium size cracks may be filled/caulked in preparation for surface coating and to keep water out of the concrete. Filling may be done with cement mortar, epoxy grout, polyurethane joint sealant, asphaltic or rubberized sealers, or other quality commercial products suitable to the application. Flexible material should be used where movement of the concrete is expected; such as, thermal expansion and contraction, seismic motion, and vertical displacement due to settlement. Routing and cleaning the crack to prepare a good bonding surface for the sealer is the most important step in treatment of cracks.

3.2.5.3 Concrete Pile Jacket. Figure 3-5 illustrates a timber jacket for precast concrete piles to protect the pile against abrasive damage caused by ice. Reference 7 contains additional information with a photograph of a case where the life of piles was extended significantly by such a jacket. Two-inch lumber, with galvanized steel bands, are used with the jacket extending the length of the tidal zone.

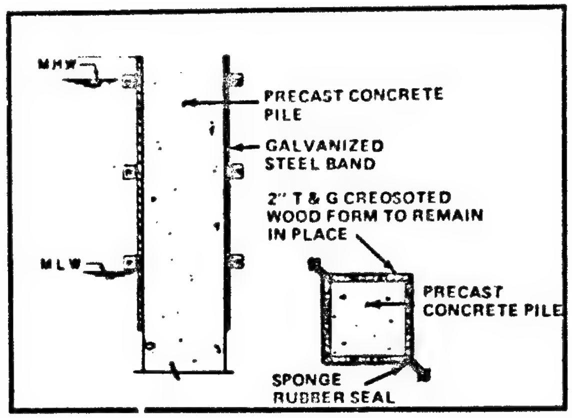


Figure 3-5. Timber Jacket on Concrete Pile.

3.3 STEEL. Steel is used extensively in construction and repair of waterfront facilities due to availability, cost, ease of fabrication, physical and mechanical properties, and design experience with its use. Structural steel and cast or fabricated steel are used in all areas of the waterfront. Typical applications include:

- Piers and wharves utilize steel H-piles or pipe piles to support or brace the structure. Steel sheet piling is used to retain fill. Structural steel shapes are used for framing.
- Bulkheads and quaywalls utilize interlocking steel sheet piling with tie rods and wales.
- Fender systems incorporate steel H-piles.
- Mooring hardware such as cleats, bollards, bitts, and chocks are made from cast or fabricated steel.
- Other items such as utility lines, grating, opening frames, manhole covers, fences, bolts and nuts, handrails, and concrete reinforcement are made of steel.
- Steel components are used in some camels.

Maintenance of steel structures and components will entail repair or replacement of damaged or corroded steel, periodic coating of steel surfaces for corrosion protection, and maintenance of cathodic protection systems. Corrosion is the major cause of the deterioration of steel structures. The extent or severity of corrosion will vary with the exposure zone of the material; that is, whether it is in the atmospheric zone, the splash or tidal zone, or the submerged zone. The selection of materials for waterfront use must consider each of these varied conditions.

The use of steel should follow design guidelines in NAVFAC Design Manuals, references 7 and 25, and the American Institute of Steel Construction's Manual of Steel Construction. The material specifications of ASTM, the American Society for Metals, and other organizations document chemical and physical characteristics of the various types of steel. Material selection and procurement should conform to these specifications.

3.3.1 Steel for Waterfront Construction. Carbon steel and carbon steel alloys are the most important types of metals used for construction of waterfront facilities. In general, only low carbon steels with a carbon content less than 0.35 percent by weight are used due to welding characteristics. Except for physical damage from impact or loading, deterioration of steel is caused only by corrosion.

3.3.1.1 Carbon Steel. Carbon steel is an alloy of iron and carbon with a carbon content less than 2 percent. The requirements for structural carbon steel are contained in ASTM A 36 and this grade is suitable for welding.

Carbon steel will corrode in all exposure zones, but the severest corrosion occurs in the splash zone and just below mean low water. Coatings or cathodic protection, or a combination of the two, are necessary to prevent excessive corrosion of steel in the waterfront environment. Coatings are covered in paragraph 3.3.3.1. Cathodic protection is covered in paragraph 3.3.3.2.

3.3.1.2 Low-Alloy Carbon Steels. Corrosion resistant, low-alloy carbon steel may be used instead of carbon steel if greater corrosion resistance is required. Low-alloy carbon steels contain small amounts of other elements such as copper, chromium, nickel, molybdenum, silicon and manganese. Up to 1.5 percent of these elements s added for increased strength or heat treatment capability. These alloys have a better resistance to corrosion because the rust does not easily break away from the metal surface. The life of a low-alloy steel may be five times as great as carbon steel.

The common low-alloy steels include ASTM A 690 (also called "Mariner steel"), A 588, A 572, and A 242. Steel conforming to ASTM A 690 is recommended for steel H-piles and sheet piling, because of its greater corrosion resistance over plain carbon steel in the splash zone. The low alloy steels offer no more resistance to corrosion than ordinary carbon steel, however, when submerged. Under this condition, the low alloy steels require coatings or cathodic protection, or both. Composite piles of A 690 and A 36 may be utilized when greater resistance in the splash zone is required. ASTM A 588 and A 242 steels are not recommended for buried structures, submerged conditions, and marine atmospheres unless they are exposed to the wind, rain, and sun.

Coatings for, and cathodic protection of, low-alloy carbon steels, are the same as for plain carbon steel as discussed in section 3.3.3.

3.3.1.3 Stainless Steels. Stainless steels have limited application in the marine environment. They do well when exposed to wind, rain, sun, or high-velocity conditions in seawater. In calm or stagnant waters, salt spray zones, or in buried conditions, corrosion is likely to occur. Stainless steels in the 300 series (302, 304, 316) are substantially more corrosion resistant than the 400 series stainless steels. Due to poor performance in marine environments

and high cost, stainless steels should only be used for specialized applications where performance has been proven by experience to be sufficiently superior to more commonly used materials to justify the high cost.

3.3.2 Deterioration of Steel. Although exposure to the atmosphere, severe temperature changes, and wind erosion all contribute to the deterioration of steel in waterfront facilities, exposure to saltwater is the major concern. Corrosion rates of metals exposed to seawater are much higher than those of similar metals exposed to freshwater.

Biological fouling, the attachment and growth of marine organisms on the steel, also contributes to increased corrosion. This type of fouling can be decreased by using antifouling coatings.

The other major causes of deterioration are wave and current effects and abrasion from objects and elements in the water.

3.3.3 Preventive Maintenance for Steel. The primary preventive measures available to increase the life of steel are protective coatings and cathodic protection. The decision of which approach to use is a function of location on the waterfront structure (submerged or not) and economics. The use of cathodic protection is restricted to submerged or buried structures.

3.3.3.1 Protective Coatings for Steel. The chief means of protecting steel from corrosion is by coating. Coatings should be free of pinholes or discontinuities to control corrosion of the underlying steel. A corrosion inhibitive pigment should be used to prevent corrosion if a break in the coating develops. Reference 26 provides a comprehensive coverage of protective coatings for steel structures.

Since unprotected steel corrodes freely in a marine environment, it is almost always coated. Sometimes, underwater portions of steel piling to receive cathodic protection are not coated. While coating of such areas is recommended, a combination of cathodic protection and coating is usually the most cost effective in the long term. Steel components of waterfront structures are best shop-coated, transported to the job site, and spot repaired, if necessary, before installation.

a. **Surface Preparation.** Irregular steel surfaces, such as welds and sharp edges, should be ground smooth before preparing the surface for coating. The steel should then be cleaned by abrasive blasting and coated as soon as possible. A high level of blast cleaning is required for coating with a high-performance coating, such as epoxy or coal tar epoxy. Lower performance coatings or less severe environments require a lower level of surface preparation. Recommendations for the various levels of cleanliness as defined by SSPC are as follows (see appendix A):

Coating System	Immersed, Splash, or Tidal Area	Less Severe Areas Above Water
Alkyd	Not recommended	SSPC SP-10 or SP-6
Coal Tar	Not recommended	SSPC SP-6
Epoxy	SSPC SP-5 or 10	SSPC SP-10
Coal Tar Epoxy	SSPC SP-5 or 10	SSPC SP-10

b. **Recommended Coatings.** See appendix A for titles of specifications referenced. **Epoxy polyamide** (3 coats of MIL-P-24441) or **coal tar epoxy polyamide** (2 coats of SSPC Paint No. 16 or Corps of Engineers C-200) are recommended for piling and other steel structures which are to be immersed in seawater. Coal tar epoxies become brittle from prolonged exposure in direct sunlight, and are not recommended for this exposure. Epoxies perform well in direct sunlight except for chalking. If chalking is objectionable, substitute a coat of **aliphatic polyurethane** (MIL-C-83286) for the third coat of epoxy polyamide to obtain excellent weathering in direct sunlight.

For milder atmospheric exposures, an **alkyd system** (1 coat of TT-P-645 primer and 2 topcoats of TT-E-490) will provide adequate protection.

Coal tar coatings (MIL-C-18480) are occasionally used for **temporary protection** over marginally prepared surfaces. They provide good temporary protection until a more permanent coating system can be applied. They may also be used as a dip coating for components such as chain that are difficult to coat otherwise.

All of the above coatings can be applied by brush, roller, or spray, but brushing of the prime coats onto the steel will achieve surface penetration. Adjacent coats should be applied on successive days. Instructions for application of MIL-P-24441 can be found in Chapter 631 of Naval Ships' Technical Manual NAVSEA S9086-VD-STM-000 (reference 27). Instructions for applying SSPC Paint No 16 can be found in Steel Structures Painting Manual Vol 2, Systems and Specifications (reference 28).

3.3.3.2 Cathodic Protection of Steel. The natural corrosion of steel structures immersed in water or buried in soil can effectively be controlled by the use of anodes and direct current systems to minimize or stop the corrosion process, by establishing the steel as a cathode. Cathodic protection systems are best installed when the structure is constructed, but can be added to existing structures. They can effectively stop corrosion but cannot restore the material already lost by corrosion. Design of cathodic protection systems is contained in reference 29. Maintenance of cathodic protection systems is covered in reference 30.

a. **Galvanic Anode Systems.** Galvanic anode cathodic protection systems rely upon the corrosion of active metals such as zinc, magnesium or aluminum to generate the electrical current needed to protect buried or submerged steel structures. Since these anodes are sacrificed to protect the structure, they

are known as sacrificial anodes. The anodes must be buried or submerged near the structure to be protected and electrically connected to it with a low resistance bond. As the anodes are consumed in providing protection, they must be periodically monitored and replaced when over 80 percent of the metal is consumed, or when they will be consumed before the next scheduled inspection. The level of protection provided can be determined by measuring the potential between the structure being protected compared to a standard reference electrode.

b. **Impressed Current Systems.** Impressed current cathodic protection systems use an external source of electrical alternating current, and a rectifier, to provide the protective direct current to be impressed across the system. This system also requires anodes buried or submerged in the vicinity of the structure being protected, but these anodes can last much longer than galvanic anodes, since they only conduct the protective current into the water or soil and are not the source of the current. Impressed current cathodic protection systems also require periodic inspection and maintenance to ensure effectiveness in controlling corrosion.

3.4 NONFERROUS METALS AND ALLOYS. A variety of materials are available which, if used properly, are more resistant to corrosion by seawater and marine atmosphere than steel. These materials are used for specialized applications and are not used as much as steel due to higher costs. The common nonferrous metals are aluminum, copper, nickel, titanium, and alloys of each.

3.4.1 Aluminum. Many alloys of aluminum are available for applications requiring high corrosion resistance to the marine atmosphere as well as good strength-to-weight ratios. The common uses of aluminum at the waterfront include:

- Brows and platforms
- Decking and catwalks
- Light poles and bases

Aluminum should not be used as a substitute for steel solely for its corrosion resistance quality. Aluminum and its alloys are subject to pitting and crevice corrosion in marine environments, especially in submerged conditions. If pitting can be tolerated and crevices eliminated, aluminum alloys may be used successfully where low weight and other unique properties are required.

ASTM specifications define compositions and mechanical properties of aluminum alloys. Alloys 5083, 5086, 5052 and 6061 are the most popular alloys for structures exposed to the marine atmosphere.

3.4.2 Copper. Copper and copper alloys are suitable for waterfront usage because of their uniform, low corrosion rate. Copper is commonly used for electrical conductors, pipe, sheathing, and many hidden uses on supporting equipment at the waterfront. The copper alloys most commonly selected for marine corrosion resistance are copper, cupro-nickel 90-10, cupro-nickel 70-30, arsenical admiralty brass and most true (zincless) bronzes. These alloys form films of corrosion products which provide protection even in flowing water.

3.4.3 Nickel. Nickel base alloys have good corrosion resistance to seawater and to cavitation damage. These materials are used for specialized applications in springs, cable connectors, expansion joints, rupture disks, valves, fasteners, heat exchangers, and piping. The high cost of these materials makes them unsuitable for bulk construction at the waterfront.

The most common nickel alloys used are Inconel alloy 625 (nickel-chrome alloy), Hastelloy alloy "C" (nickel-chrome-molybdenum alloy), and Monel 400 (nickel-copper alloy). Inconel and Hastelloy "C" are essentially immune to corrosion in marine environments. Monel 400 has good corrosion resistance when it has been cathodically protected with a more active metal. If not protected, Monel will develop pitting and crevices.

3.4.4 Deterioration of Nonferrous Metals and Alloys. Nonferrous metals and alloys will corrode and develop pits and crevices under normal atmospheric conditions. In general, these metals are not given preservative coatings, but may be painted for color/appearance in certain uses. Corrosion rates can be greatly accelerated when two or more dissimilar metals are in contact with each other and exposed to a corrosive environment. Particularly when they are buried or submerged, accelerated corrosion of one of the metals can occur due to an electrochemical reaction called galvanic corrosion. Galvanic corrosion rates depend on the metals' electrical properties and the medium in which the metals are exposed. Galvanic series tables have been developed indicating lists of metals in order of decreasing corrodibility when exposed to a certain solution or medium. Generally, the closer one metal is to another in the galvanic series, the lower the corrosion rate with the more active metal, and conversely, the further apart, the greater will be the corrosion rate of this metal.

3.4.5 Preventive Maintenance for Nonferrous Metals and Alloys. PM measures to be taken will depend on whether or not dissimilar materials are involved.

a. **Similar Nonferrous Metals and Alloys.** The only formal PM measure to be taken is regular and careful inspection to determine condition of the component. In the later part of a component's life expectancy, it may prove economical to coat the metal to prevent further corrosion rather than to replace the component.

b. **Avoiding Galvanic Corrosion.** Galvanic corrosion can effectively be eliminated by making the structure out of as much of the same metal as possible, placing a protective insulator between the two dissimilar metals, and by providing cathodic protection if buried or immersed. When galvanic corrosion cannot be effectively eliminated it can be reduced by the appropriate use of protective coatings on the steel, ensuring not to coat the anodes. Detailed information on treatments of galvanic corrosion is given in MIL-STD-889 for metal exposed to saltwater environments.

If dissimilar metals must be joined, the following preventive measures should be taken:

- Choose metals close together in the galvanic series.

- Keep the cathodic area small in relation to the anode area; for instance, bolts or screws of stainless steel for fastening aluminum sheets, but not the reverse.

- Provide a protective insulator between the two metals.

- Use special coatings on the metals.

3.5 SYNTHETIC MATERIALS. Numerous synthetic materials are used in waterfront facilities and components. They are extremely versatile in application and serve as a structural material, coating material, or buoyancy material. In general, these materials do not corrode in the marine environment, but deteriorate due to other reasons such as water absorption and swelling and degradation by ultraviolet light. The common synthetic materials include fiber-reinforced plastics (FRP), foams, rubbers and elastomers, plastic pile wraps and piping, synthetic fibers, and adhesives.

Deterioration of these synthetics, other than physical damage, increases with aging; plastics crack or separate, some types become brittle, foams crumble with age and lose resiliency, elastomers stretch and deteriorate from the effects of sun and exposure. In general, no preventive maintenance measures are performed other than inspection. Certain materials and components can be economically repaired when damaged.

3.5.1 Fiber-reinforced Plastics. FRP are used for applications requiring high strength-to-weight ratios and resistance to deterioration, such as:

- Pile jackets for steel and timber piling to reduce corrosion, erosion, and marine borer attack.

- Lightweight, sandwich construction for small buildings and containerization.

- Floating structures, such as buoys and landing floats, when used in combination with closed-cell foams.

- Deck hardware such as lighting posts, grating and handrails on piers.

- Filament wound piping for lightweight, low temperature pipelines transporting steam condensate, seawater, freshwater, sewage, oil, and potable water.

Fiber-reinforced plastics are a composite of resin and fibrous material. The common resins are polyester and epoxy. Polyester resins are general purpose resins that cost less than epoxy. Epoxy resins have superior strength properties, greater resistance to chemical and water degradation, and lower shrinkage during curing.

Materials used as reinforcement for FRP include continuous strands, woven cloth, chopped fibers, and in some cases glass flakes.

3.5.2 Foams. Foams are utilized at the waterfront as a filler material for sandwich construction, to provide buoyancy for buoys, landing floats and floating brows, and in foam-filled fenders to absorb the energy of berthing ships. Foams are resistant to deterioration in the marine environment provided they are encased in some impermeable, marine resistant layer.

The common foams are polyurethane, polystyrene, and polyethylene. Polyurethane foams can be foamed in place and are most useful in public works. The disadvantages of polyurethane foam are its instability when exposed to direct sunlight and its flammability.

Polystyrene foams are relatively inexpensive compared to polyurethane. They can be purchased in large quantities and cut to shape. Polystyrene foams are used in decks for buoyancy of small boat moorings in marinas.

Polyethylene foams are used in foam-filled fenders. The foam, encased in an elastomer cover, absorbs the energy of impact of berthing ships.

3.5.3 Rubber and Elastomers. Numerous natural and synthetic rubbers and elastomers are used at the waterfront in hoselines, gaskets. fender system components, and other specialized applications. These materials are resistant to the marine environment provided the appropriate rubber or elastomer is used. The more common material is a urethane elastomer as used for the shell of foam-filled fenders.

3.5.4 Other Synthetic Materials. Synthetic materials are also used at the waterfront for pile wraps, piping, and adhesives. Pile wraps are made of flexible polyvinyl chloride (PVC) films and prevent growth of wood boring organisms. PVC piping is widely used for numerous applications, as it is lightweight and corrosion resistant. Some degradation of the piping will occur if exposed to sunlight and other weathering factors. Normally, PVC pipe becomes brittle as it ages.

Adhesives, coatings and putties made from epoxy have been developed for bonding to damp and underwater surfaces. They are used to bond structures or components, connections, joints and other metal configurations susceptible to corrosion, to fill voids, and to protect surfaces. They can also be used to patch holes above or underwater.

3.6 CUT STONE, RUBBLE, RIPRAP, AND SOIL. These types of materials are used extensively in coastal protection structures, harbor shoreline structures, and as fill and protective materials for wharves, quaywalls, mole piers, caissons, and cofferdams. All of the materials discussed in this section are natural, except the manmade concrete armor units. The most common uses include:

- Cut Stone - graving docks, quaywalls, and seawalls.
- Rubble and Riprap - breakwaters, seawalls, groins, jetties, fill and protective material at the toe of walls and under piers.
- Soil - backfill behind shoreline walls, solid fill/mole piers, dikes and levees, fill material, and a component of breakwaters and groins.

The following paragraphs describe these materials in the forms more usually found in waterfront facilities. The causes of damage and deterioration of structures constructed of these materials, and maintenance and repair of the structures, are covered in chapter 10.

3.6.1 Cut Stone. Most of the structures utilizing cut stone blocks were constructed in the 19th century. Granite is the predominant type of stone. Until the 1850s, the blocks were set in lime mortar, but after that portland cement mortar was used. The stone itself is not subject to deterioration that can be decreased by preventive maintenance measures. High quality stone blocks retain their sharp edges and corners and structural integrity for many years. Therefore, the maintenance concerns of stone masonry center around settlement, joint leakage, scouring, and displacement.

3.6.2 Rubble and Riprap. Rubble is irregularly shaped, rough stones, ranging in size up to 1,000 cubic feet each and in weight up to nearly 90 tons each. The stones are in the same condition as when quarried without preparation other than removal of sharp angles and objectionable protruding points. Hard rock, which is more desirable, usually consists of either granite or traprock (fine-grained igneous rock). Limestone, dolomite, and sandstone are undesirable because of their lesser hardness, toughness, and durability.

Since the rubble used as riprap must be available in large sizes, the quality, condition, and shape of stone are important. Each piece should be devoid of planes of weakness, have a specific gravity not less than 2.6, and have excellent resistance to abrasion and weathering. Massive, compact, fine-grained igneous rock is the best source of rubble.

Riprap is a mixed assemblage of rubble, either dumped indiscriminately as a foundation for the waterfront structure from scows and barges, or deposited on the surface of a mound to protect against erosion by waves and scouring by tidal action and underwater currents. Where it can be procured in large quantities at low cost, riprap can be useful as a filter blanket over a sandy bottom, as fill behind moles and quaywalls, and as protection for the sloping sides of mounds. Riprap submerged en masse weighs no more than earthen fill and rests at a steeper slope, approximately 1.25 to 1, than does earth. The riprap in older breakwaters consists of large cubical or rectilinear blocks of quarried stone.

The necessary characteristics of the stone are durability, soundness, and hardness, so that it resists abrasion. All types of available stone are used, but the most desireable are granite, basalt, and carbonate stone. The better types are denser, causing a more severe handling and transport problem.

3.6.2.1 Concrete Armor Units. Many different concrete shapes have been developed as armor units for rubble structures. The more prevalent types are shown in figure 3-6. The major advantage is that the units interlock, permitting use of steeper structure side slopes or a lighter weight of armor unit. This property is especially valuable when quarrystone of the required size is not available. Smaller concrete armor units can often be substituted for larger quarry stones and still obtain comparable protection of the mound of rubble. No reinforcing steel or steel lifting eyes are usually required in

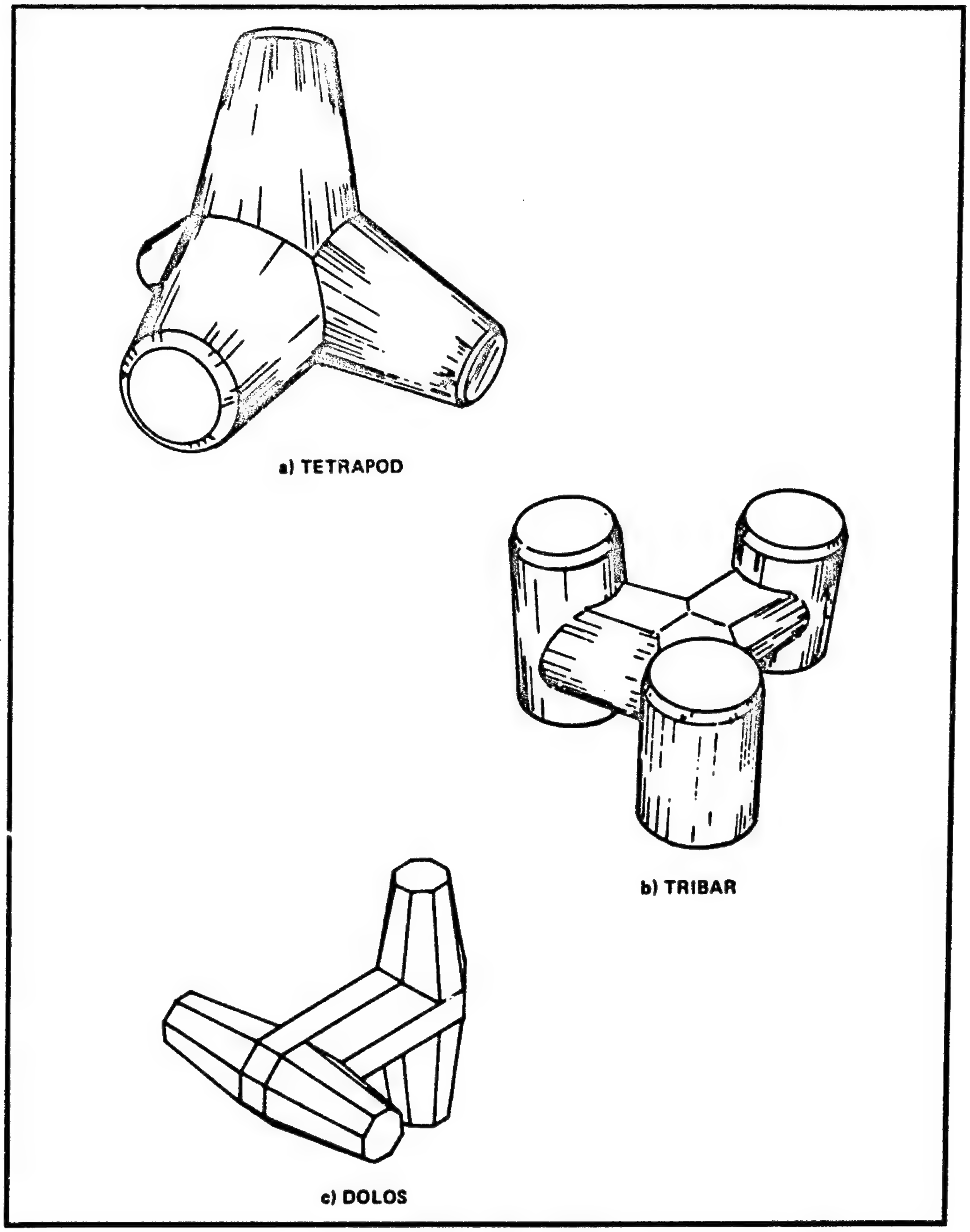


Figure 3-6 Concrete Armor Units.

dolosse and tetrapods; consequently, corrosion is not a problem and unit cost is minimized. Dolos and tetrapod units are less vulnerable to damage during placement and storms than the various other types of concrete armor units. The Army Engineer Waterways Experiment Station considers the dolos armor unit the most efficient.

The technique of placement and the size of the armor unit will determine if reinforcing is required in dolos or tribar units. Heavy units, exceeding about 20 tons, will require reinforcing if placed from a landside unit. Placing armor units from floating equipment, where the wave action may cause bumping of the units, may require reinforcing in armor units as light as 10 tons.

Complete physical characteristics of these units are contained in reference 10.

3.6.3 Soil. A complete description of a soil includes classification, density, shear strength, moisture content, and mineralogic content. For soils used in waterfront structures, it is often sufficient to classify them only according to size, that is, clay, silt, sand, and gravel. The density, plasticity, and moisture content are most important for the finer-grained soils, while soundness and gradation are most pertinent to the coarser-grained soils and rock fills. The particle size, which marks the boundary between the fine-grained, generally cohesive soils (silts and clays) and the coarse-grained, granular soils (sands and gravels), is approximately the minimum size retained on the no. 200 standard sieve. Organic soils, such as elastic silts and peats, are never used in the construction or repair of engineering structures.

Maintenance problems increase as the grain size of the soil gets smaller. Finer-grained soils in the cohesionless range are extremely susceptible to leaching and erosion, whereas fine-grained cohesive soils are more difficult to compact satisfactorily and may undergo undesirable shrinkage and/or swelling behavior. With granular soils, gradation is important. Uniformly graded soils with a narrow range of particle sizes are difficult to compact, are extremely porous, and obtain lower densities and strengths than soils with a broader distribution of particle sizes. However, where compaction of sands and gravels is involved, the presence of large, oversize cobbles can interfere with the compaction of the finer materials present. Such larger particles should be excluded from the compacted fills and used as riprap or slope protection.

CHAPTER 4. SAFETY

4.1 INTRODUCTION. A diversity of types of work containing elements hazardous to personnel, equipment, and property are performed at the waterfront during maintenance and repair of facilities. This chapter highlights the major areas of safety and references other publications for use by safety and supervisory personnel.

4.2 RESPONSIBILITIES. Responsibility for safety lies with each individual during all phases of maintenance and repair functions. Safety is an integral part of the work to be accomplished. Therefore, it must be considered in job planning and throughout execution. The following are the primary references applicable to safety in waterfront construction and operations:

a. US Department of the Army, EM 385-1-1: General Safety Requirements Manual (reference 31).

b. Technical Manual, NAVAIR A1-NAOSH-SAF 000/P-5100-1, Naval Air Systems Command, Washington, DC, Feb 1986 (reference 32).

c. US Department of the Air Force Manual AFM 127-101: Industrial Safety Accident Prevention Handbook (reference 33).

d. Shipyard Industry, Occupational Safety and Health Administration (OSHA) Safety and Health Standards, OSHA 2268 (reference 34). This book contains information on welding, abrasives blasting and painting, and life saving equipment.

4.3 PLANNING FOR SAFETY. Safety aspects must be an integral part of planning for accomplishment of all repair jobs. Planning should include a review of the job site, the schedule of normal port operations in the vicinity, and lessons learned from similar work in the past. Specific items that should be planned out in advance and made a part of the job execution order include:

- Vehicle and pedestrian traffic patterns, how they will be affected, and control at the job site.
- Requirement for barricades and their layout.
- Location of high work scaffolding and safety aspects of the surrounding area.
- Potential fire hazards at the site and the need for fire extinguishers.
- Requirements for safety signs and optimum locations.
- Excavations that may require unusual safety measures and barricading.
- Requirements for safety and warning lights.
- Requirements for welding, abrasive blasting, air/water jet operations, or pneumatically-placed concrete, and the need for protective measures.
- A list of special safety equipment required at the work site.

4.4 PERSONNEL PROTECTION. Personnel protective devices, when required, should be of safe design and meet applicable OSHA regulations. The devices include high work equipment, life jackets, protective equipment for eyes, face, ears, head and extremities, protective clothing, respiration devices, and protective shields and barriers. Some of the more general personnel safety precautions are:

- Use life belts or safety belts when performing high work. Never use a loop of rope around a person's body as a life belt. Rig safety belts with as little slack as possible.
- Use hard hats, unless they are clearly unnecessary.
- Use eye and face protective device when hazards of flying objects, glare, harmful liquids or gases, injurious radiation, or a combination of these hazards exists.
- Use appropriate gloves when handling hot, cold, abrasive, and hazardous materials.
- Use ear protection when levels of 85 dBA or more are experienced within the work site for extended periods.
- Use safety shoes when at the job site.
- Use respirator when air is contaminated with harmful dusts, fumes, or gases.
- Always use protective shields that have been installed on power machinery.
- Use life jackets approved by the Coast Guard when required.

Some materials handled during construction, maintenance and repair work may be hazardous to personnel. These materials should be immediately identified, labelled, and properly handled during use, storage and disposal. Wood preservatives, solvents, coatings, and caustics make up the major portion of the hazardous material used. Good ventilation, proper clothing, and personnel safety devices should be used when handling these materials. Items saturated with hazardous material should be disposed of properly. If the saturated item is an article of clothing, it should be removed immediately and replaced with clean clothing. Personnel should wash to remove all contaminants that may have come in contact with their body. Skin or eye contact, inhalation, or ingestion of hazardous materials should be avoided. Personnel working with the materials should be familiar with emergency treatment procedures.

4.5 FIRE SAFETY. Fire safety cannot be overemphasized. It is one of the most prevalent hazards in many types of work and can be costly both in terms of life and property.

Some general fire prevention precautions are listed below.

- Know the type of activities occurring on the pier including flammable and combustible materials storage and general storage.

- Know the fire protection capabilities installed on the pier.

- Keep fire lanes clear on the pier.

- Locate approved portable fire extinguishers of the appropriate size, type, and number in conspicuous places at the job site to match the work requirements.

- Service the fire extinguishers on a regular basis.

- Maintain a training program instructing personnel in fire prevention and responsibilities during fires.

- Establish areas where open flames constitute a hazard, and post these areas with no smoking or open flame signs.

- Ground all electrical equipment.

- Provide good ventilation in all enclosed areas.

For a full understanding of fire hazards and fire prevention procedures, see:

- National Fire Protection Association (NFPA) Fire Protection Handbook.

- NFPA 30, Flammable and Combustible Liquids Code.

- NFPA 87, Standard for the Construction and Protection of Piers and Wharves.

- NFPA 231, Standard for General Storage.

4.6 WORK SITE SAFETY. Safety at the maintenance/repair site may have elements of general construction, steel erection, and traffic safety requirements. Specialized and detailed areas of safety that may be involved include crane rigging and lifting operations, high work, welding and cutting, underwater operations, excavation, air and water jet operations, and surface water safety. These specialized areas of work are discussed in paragraph 4.7. Numerous safety manuals and publications provide detailed procedures and regulations for these types of work.

The following are the major general areas of work site safety:

a. Housekeeping is important. Keep materials well sorted and stacked. Remove excess items. Keep discarded items and trash picked up. Watch for tripping hazards. Keep walkways reasonably free of oil, grease, or water. Spills must be cleaned up promptly.

b. Post a sign or tag at the site under the following conditions.

- Use "DANGER" signs only where an immediate hazard exists.

- Use "CAUTION" signs only to warn against potential hazards or to warn against unsafe work practices.

- Use accident prevention tags to control specific hazards. Include the following information on the tag:

  - reason for placing the tag
  - name of person placing the tag
  - date the tag was placed

c. Post the site with a hardhat caution sign for all personnel in the area, including visitors.

d. Designate and mark vehicle and construction equipment traffic lanes and areas.

e. Hand and power tools should be kept in good working condition and used only for the purpose for which they are intended and only by workers qualified to use them.

f. Do not use compressed gas to blow dirt, chips, or dust from clothing when pressure is greater than 10 pounds per square inch.

g. Personnel working near or over water should wear US Coast Guard approved lifejackets. Ring buoys with at least 90 feet of line should be available for emergency rescues.

h. Ramps or walkways should be of adequate strength, provided with side boards, well maintained, and properly secured.

4.6.1 Barricades. All unsafe traffic areas, such as openings, interruptions, and breaks in deckings, roadways, or walkways should be completely surrounded by adequate barricades. The barricades should be set back away from the edge of the opening so that no person or vehicle can fall into the opening. The barricades should display plain, legible signs and lights to warn of the danger. If work of a particularly hazardous nature is being done on a deck, ground surface, or overhead structure or bulkhead, the affected area should be barricaded until it is safe for traffic to proceed. Welding at or near the vehicular or pedestrian traffic area should be completely surrounded by a solid shield high enough to prevent direct view of the flame or arc.

4.6.2 Traffic Control. Traffic on land and water, in and out and around a waterfront area, is of prime importance. Maintenance or repair operations should be organized in such a manner as to minimize traffic inconvenience, including interference with cranes. If it is necessary for a repair operation to restrict traffic, the operation should be planned and the required barricades constructed so that, in case of an emergency, operations can be stopped and barricades removed in a reasonably short time. If repairs undertaken as a whole will restrict traffic, the repairs should be done in parts, if possible, so as to offer the least hindrance to traffic and base operation. If normal traffic must be restricted in an area for an extended amount of time, the traffic should be rerouted around the work site with barricades and signs indicating the new route direction.

4.7 SPECIFIC AREAS OF SAFETY CONCERN. The following paragraphs describe specific areas of work at a waterfront facility and safety precautions that should be followed when performing such work.

4.7.1 Underwater Operations. Inspection, maintenance, and repair work performed below the water surface require strict safety precautions which must be followed to the highest possible level. All underwater work must be planned in detail and a high level of equipment inspection maintained. Underwater equipment should be of the highest quality and in good working condition. Any defective or otherwise faulty equipment should be immediately removed from service and repaired or replaced. Divers performing underwater work must be certified, experienced in construction, and familiar with construction tools, materials, and safety precautions established by commercial practices, OSHA diving regulations, and the Navy Diving Manual. Some of the more general safety precautions in diving operations are:

- Report all abnormal symptoms to the medical officer.
- Always display the diving flag at the dive site.
- Before a diver enters the water, check to see that all diving equipment is intact and securely fastened.
- Make water entries from the safest and easiest place near the site.
- Never free dive in water with a current greater than 2 knots unless tended from the surface.
- Always use the buddy system.
- Keep a log of all diving operations.
- Never exceed the "NO DECOMPRESSION" limits.
- Have a first aid kit and oxygen resuscitator at the site.

4.7.2 Excavation. Excavation for repair work is normally required for access to underground installations. The safety of personnel, structures, and underground installations during excavation is of prime consideration. Excavations should be made so that the surrounding ground does not lose stability or such support it may be giving to adjacent structures. If it is apparent that the surrounding ground is unstable, proper means must be provided to restrain or stabilize the movement of the soil. Necessary measures should be taken and careful observations made to be sure mud, silt, water slurry, and other excavation materials do not undermine adjacent roads, piers, fills, tracks, and facilities. Below are some general safety precautions that should be utilized during excavation:

- Prior to excavation, determine whether underground installations will be encountered and if so, where such installations are located.
- Notify appropriate utility company if excavation is proposed near their underground installations.
- Use extreme care when excavating around "live" underground electrical lines or any other installation.
- Remove trees, boulders, and other obstacles if they may create a hazard during excavation.

- Keep dust to a minimum using water or other means.

- Install barriers or barricades around the site (see 4.6.1).

- Cover small excavation holes with plywood or metal sheets capable of supporting loads that may be encountered during normal repair operations.

4.7.3 Rigging and Crane Operations. The use of cranes occurs frequently in waterfront repair operations. It is imperative that all crane personnel be thoroughly familiar with the safety precautions associated with cranes and rigging. Approximately 80 percent of all accidents involving cranes are caused by unsafe practices of operators, maintenance personnel, and others involved in the operation, such as riggers and signalmen. It is entirely possible for such personnel to perform their tasks in an unsafe manner over a long period of time without accidents and in the process become convinced that their unsafe practices are actually safe. For this reason, a continuing program of indoctrination designed to increase safety awareness is of paramount importance. Unsafe equipment rigging also accounts for many crane accidents and a rigorous inspection and maintenance program must be followed. Some of the more pertinent areas of concern in rigging and crane safety are as follows:

a. A comprehensive crane testing and certification program should be established and followed.

b. When a mobile crane is mounted on a barge, a modified load rating chart should be provided that will limit the list of the barge under load to about five degrees. Under no circumstances shall the modified load rating exceed the original capacity specified by the manufacturer.

c. Operators must thoroughly test and inspect all wire rope.

d. Riggers must use only approved rigging gear and methods.

e. Crane operators should be tested and licensed in accordance with applicable requirements.

f. Safety operating procedures for cranes are numerous. A few of the more pertinent are:

- Secure the boom of mobile cranes in line with the direction of motion when in transit.

- Secure the empty hook or block from swinging freely.

- Avoid sudden stops when rotating the crane.

- Use restraining lines when rotation of the load is hazardous.

- Do not lower the load or the boom below the point where less than two full wraps of wire rope remain on the drum.

- Raise and lower loads and move crane only when directed by an authorized signalman. The signals used must be thoroughly understood by both the operator and the signalman. The signalman should wear a hardhat of some distinctive color that will readily identify him as the signalman.

- Do not handle a load which exceeds the rated capacity of the crane. If weight of the load is in doubt, proceed with caution.

- Allow no one under a suspended load.

- Allow no one to ride on crane loads or hooks.

- Operate no crane with the boom within 10 feet of any overhead wires.

- Do not permit freefall boom operation at any time.

- Make sure all limit switches and other safeguards are operable.

- Use outriggers when the load to be handled exceeds the safe working load without outriggers.

4.7.4 High Work. High work must be well planned and taken very seriously by personnel performing the work. Personnel should be experienced in high work and familiar with the use of construction equipment. Equipment used to perform high work should be of good commercial quality and conform to all military and OSHA regulations. The following are some general safety precautions to be taken when performing high work:

- Work above 5 feet must have scaffolding provided.

- People working above 12 feet must have a safety belt and lifeline.

- Ground personnel must be kept clear of high work as much as possible.

- Inspect equipment daily before starting work and immediately correct deficiencies.

- Use handlines for raising and lowering objects and tools.

- Do not paint high work equipment since painting may conceal defects.

- Lock casters or wheels before ascending onto equipment.

- Post caution signs around high work areas.

4.7.4.1 Ladders. Personnel using ladders should be familiar with each type and its uses. Ladders made on the job for a particular use should be rigid, complete, and able to support the intended load. Ladders should be placed on flat solid ground. Wet areas and soft loose dirt should be avoided when positioning a ladder unless means are provided to stabilize the soil. If the stability of the ladder is in jeopardy, it should be tied, blocked, or otherwise

secured to prevent displacement. Proper maintenance and treatment of the ladders should be provided to prevent rotting and drying out. Splinters, burrs, and sharp edges on metal or wood ladders should be removed and made smooth. Defective ladders should be removed from service and a tag or sign placed in a conspicuous place indicating the defect. Some of the more general safety precautions when using a ladder are:

- Use both hands when ascending or descending a ladder.
- Keep ladder rungs free of oil and grease.
- Not more than one person shall mount a ladder at a time.
- Face ladder when ascending or descending.
- Do not splice ladders together.
- Do not use the top step of a ladder as a step.
- Do not use metal ladders where they can come into contact with electrical circuits. Mark metal ladder with a caution sign indicating this caution.

4.7.4.2 Scaffolding. Scaffolds should be built to suit the particular work. They should be rigid and completely stable in themselves, even when not secured to a structure. No less than two 10-inch-wide planks of 2-inch nominal thickness should be used as the wood scaffolding platform. The unsupported span shall not exceed 10 feet. All scaffold planks should be free of large knots, shakes, splits, checks, or any other visible defects. All scaffold planks should be securely fastened. Any scaffold plank that, by use or accident, becomes broken, cracked, warped, or in any way defective should be replaced immediately by a sound plank. Pipe scaffolds should be free of any bent, dented, or otherwise defective members. Every connector of each tier must be made tight before the next tier is installed. Joints and connectors in pipe scaffolds must be tightly bolted. Scaffold supports should be maintained in a vertical position. Scaffold flooring should have footrails installed to prevent tools from being knocked off. The brakes of portable scaffolds should be locked when personnel are onboard.

Convenient access from the ground and from one level to another should be provided by ladders or stairs that are rigidly secured. All platform levels should have well-supported guard rails. On the land side, supports must be placed on firm ground, preferably in such a manner that they can be wedged up or raised if necessary. If vehicles will pass adjacent to or near the scaffolding, substantial barricades should be placed at least 3 feet from the supports of the scaffold.

Fire extinguishers of adequate size shall be stationed near wood scaffolds to conform with fire regulations.

Platform planking and guard rails for hung scaffolds should be similar to those for built-up scaffolds. The rope or line used should be of more than ample size and free of defects, and it should be secured to cleats, bitts, a

string piece, or another substantial part of the structure. The scaffolds should also be equipped with a positive mechanical or structural means of belaying the free end of the rope or line.

4.7.5 Air and Water Jet Operations. Air and water jet operations are inherently hazardous to people performing the work and others in the area. Special safety precautions are necessary and continuous attention to safety must be given whenever air and water jet operations are in process. This work includes abrasive and water jet blasting, spray painting, and shotcrete operations. Some of the more pertinent safety concerns are as follows:

a. Condition of the equipment is particularly important in air and water jet operations. Prior to beginning work each day, a rigorous and enforced inspection routine is necessary. No compromises in use of faulty or questionable equipment should be allowed.

b. Protective clothing and equipment must be considered an integral part of the equipment in these operations, including hardhats, goggles, respirators, masks, shoes, gloves, and protective wearing apparel.

c. Work areas should be marked with caution or danger signs and all unnecessary personnel kept from the area.

d. A supervisor should be present whenever air or water jet operations are in progress to watch for hazards and enforce safety practices.

e. Communication between the blaster and machine operator must be maintained. If within sight of each other, well defined hand signals may be used. A deadman control device is required on blasting nozzles that will positively stop air and material flow when released.

f. Airless spray painting is inherently more dangerous than other types of painting and should be treated accordingly. Familiarity and skill with the work can cause laxness in precautions taken which must be guarded against.

g. Removal of paint from wood by torch is prohibited.

4.7.6 Welding and Cutting. Safety precautions required for this work are extensive and specialized. One point to keep in mind is that welding safety must be concerned with other people in the construction area as well as people performing the work. The following lists some of the more basic precautions and procedures, for detailed safety precautions see reference 35.

- The primary hazards for which protection must be provided are:
    - eye injury
    - burns
    - toxic vapors
    - electric shock (when applicable)
    - fire and explosion
- All welding equipment should be inspected daily. Remove defective items from service.
- Light torches only with approved devices, never matches.

- Personnel protective equipment and clothing must be considered an integral part of the work and be inspected and maintained accordingly. No compromises in the protection of welders should ever be allowed.

- Areas should be marked with "Danger - Welding" and "Eye Hazard Area" signs.

- Welders working above 5 feet must be protected by railings and/or safety belts and lifelines.

- Do not weld where flammable paint or coating may cause a hazard or near combustible material.

- After welding is completed, mark the area of hot metal or provide some means of warning other workers.

4.7.7 Surface Water Operations. Many surface water hazards are caused by careless use and operation of surface craft, poor judgment of sea conditions and improper mooring of craft. The following paragraphs describe safety precautions for surface craft and sea conditions that must be considered when performing maintenance and repair work.

4.7.7.1 Rafts and Barges. Maintenance and repair work performed afloat on barges or rafts requires skill and knowledge of boat operations, sea conditions, berthing operations, and general safety precautions to maintain a high level of personnel safety. Some of the more common safety precautions are:

- Use only experienced and qualified personnel to operate rafts or barges.

- Abort all operations if weather or sea conditions are hazardous to personnel.

- Maintain good housekeeping on craft deck.

- Wipe up water, oil or solvent spills immediately.

- Walk on deck, "DON'T RUN".

- Cover all floor openings or post off with railing.

- Replace broken or cracked planks.

- Firmly secure raft or barge to pier.

- Wear lifejackets when afloat.

Anchoring or mooring of craft or workbarges must vary with the nature of the work and take into account the rise and fall of the tide, currents, wind, waves, and traffic. The lines must be placed so that they will not be fouled by traffic using regular channels. Proper signals and lights must be displayed on craft anchored in a channel or turning basin. The mooring system should have sufficient reserve to allow for a sudden change in weather. All lines

should be secured in such a manner that they are easily accessible and can be quickly let out or hauled in. Rafts tied alongside a structure should have fenders to prevent damage to the structure or raft. If weather predictions are such that damage to the raft or structure could happen, additional anchors or lines should be put out or the raft moved to a sheltered area.

4.7.7.2 Currents and Tidal Changes. All supervisors of the repair force should be thoroughly familiar with currents in the river, harbor, or seafront on which a repair site is located. The velocity and direction of currents can change with varying conditions of tide, wind, and rainfall. Changes in the direction of the wind can alter currents by raising or lowering the water level. Anchored or berthed vessels, if in a comparatively small or narrow waterway, can also alter the current. A chart showing direction and velocity of currents in the area should be available at every repair site.

Tidal changes at waterfronts are usually regular and predictable unless affected by wind, which can alter the range of the tide considerably. The greatest variations take place in the tidal waters of a river where the river outflow to the sea is through a widening estuary. A chart should be available at the repair site that shows the range of tides and notes conditions anticipated with various wind velocities.

CHAPTER 5. INSPECTION

5.1 GENERAL

5.1.1 The Inspection Approach. The purpose of any inspection is to provide the information necessary to assess the condition (capacity, safety, and rate of deterioration) of a structure. The usefulness of an inspection depends on establishing a clear and complete record. Although the level of inspection will determine the extent of information to be provided, in general the inspection will address the following:

INITIAL INSPECTION

a. Identification and description of all major damage and deterioration of the facility.

b. Estimate of the extent of damage and deterioration.

c. Identification of any problems associated with mobilization of equipment, personnel, and materials to accomplish repairs/maintenance.

d. Updated layouts of pile plans (which occasionally differ significantly from the drawings available at the activity).

e. Documentation of types and extent of marine growth (to help plan future inspections), as well as damage caused by their presence.

f. Water depths at each facility.

g. Water visibility, tidal range, and water current.

h. Information for the data base of waterfront facilities and data to assist in planning future inspections.

INSPECTION ASSESSMENT

i. Assessment of general physical condition including projected load capacities of the in-water structures of each facility inspected.

j. Recommendations for required maintenance and repair (M&R).

k. Budgetary estimates of costs of this M&R, including examples of the derivation of the estimates.

l. Estimate of expected life of each facility.

m. Recommendations for types and frequencies of future underwater inspections.

The underwater inspection may be accomplished by a qualified diver supervised by an engineer or by a qualified engineering diver. The structural assessment must be performed by an experienced engineer.

5.1.2 Levels of Inspection. Three basic types or levels of inspection are used for inspecting marine facilities:

a. **Level I - General Visual Inspection.** This type of inspection involves no cleaning of any structural elements and therefore is the most rapid of the three types of inspection. The purpose of the Level I inspection is to confirm as-built structural plans, provide initial input for an inspection strategy, and detect obvious major damage or deterioration due to overstress, impacts, severe corrosion, or extensive biological growth and attack.

b. **Level II - Close-Up Visual Inspection.** This level is directed toward detecting and identifying damaged/deteriorated areas which may be hidden by surface biofouling or deterioration and toward obtaining a limited amount of deterioration measurements. The data obtained should be sufficient to enable gross estimates of facility load capability. Level II examinations will often require cleaning of structural elements. Since cleaning is time consuming, it is generally restricted to areas that are critical or which may be representative of the entire structure. The amount and thoroughness of cleaning to be performed is governed by that necessary to determine the general condition of the overall facility.

c. **Level III - Highly Detailed Inspection.** This level will normally be confined to underwater inspections, and will often require the use of Non-destructive Testing (NDT) techniques. It may also require the use of partially destructive techniques such as core sampling into concrete and wood structures, physical material sampling, or surface hardness testing. The purpose of this type of evaluation is to detect hidden or interior damage, loss in cross-sectional area, and material homogeneity. A Level III examination will usually require prior cleaning. The use of NDT techniques are usually limited to key structural areas, areas that may be suspect, or to structural members which may be representative of the underwater structure. Level III inspections will require considerably more experience and training than Level I or Level II inspections, and should be accomplished by qualified engineering or nondestructive testing personnel. This type of inspection is classified as a specialized inspection within the Navy and is covered in reference (2).

5.1.3 Planning for Inspection. Table 5-1 lists the types of damage that are detectable with the three types of inspection. The levels of inspection to be used for a particular task must be decided early in the planning phase.

The time and effort required to carry out the three different levels of inspection are quite different. The time required will also depend on whether the inspection is surface or underwater, on environmental factors such as visibility, currents, wave action, water depth, severity of marine growth, and the skill and experience of the inspector. Table 5-2 provides a guide for estimating the time required to conduct Level I and Level II surface and underwater inspections.

The information for underwater inspections is based on a water depth of 30 to 40 feet; visibility of 4 to 6 feet; warm, calm water; moderate marine growth about 2 inches thick; and an experienced engineering diver or diver supervised by an engineer directing activities from the surface. For the Level II inspection, it has been assumed that 3 feet of the structural element in the splash zone, 1 foot at mid-depth, and 1 foot at the bottom, will be

Table 5-1. Capability of Each Level of Inspection for Detecting Damage to Waterfront Structures.

Level	Purpose	Detectable Defects		
		Steel	Concrete	Wood
I	General visual to confirm as-built condition and detect severe damage	Extensive corrosion Severe mechanical damage	Major spalling and cracking	Major losses of wood due to marine borers Broken piles Severe abrasion
II	Detect surface defects normally obscured by marine growth	Moderate mechanical damage Major pitting	Surface cracking and crumbling Rust straining Exposed rebar	External pile diameter reduction due to marine borers Splintered piling Loss of bolts and fasteners Early borer and insect infestation
III	Detect hidden and beginning damage	Reduced thickness of material	Location of rebar Beginning corrosion of rebar Internal voids Change in material strength	Internal damage due to marine borers (internal voids) Decrease in material strength

completely cleaned of marine growth. It has also been assumed that the most efficient method of removing marine growth will be used.

Level III inspections depend on the extent of existing damage, the type of inspection techniques, and the equipment used (ultrasonic thickness measurements, increment borings, caliper measurements). Therefore, estimates of time for Level III inspection are not included in table 5-2.

5.1.3.1 Inspection Frequency. The frequency of inspection will be dependent upon whether the inspection is surface or underwater and the expected rate of deterioration and damage. A typical example requiring more frequent inspection is an area experiencing damage by ships berthing that results in advanced deterioration to both fender and structural piling. The frequency and level

Table 5-2. Production Rate for Surface and Underwater Inspection of Structural Elements.

Structural Element	Inspection Time Per Structural Element (minutes)			
	Level I		Level II	
	Surface	U/W	Surface	U/W
12-in steel H-pile	2	5	15	30
12-in wide strip of steel sheet pile	1	3	8	15
12-in square concrete pile	2	4	12	25
12-in wide strip of concrete sheet pile	1	3	8	15
12-in diameter timber pile	2	4	10	20
12-in wide strip of timber sheet pile	1	3	7	15

of inspection should, therefore, be closely tied to the historical deterioration rate of the facility. Recommended frequencies are being incorporated into volume 4 of the updated version of reference 2. Other Navy research is currently being conducted, designed to optimize the underwater inspection frequency. The results of this research are planned for release in Fiscal Year 88. In the interim:

a. All superstructure and piling/sheet piling above the waterline, including the splash and tidal zones (figure 5-1), should be inspected annually.

b. All underwater structural members should be inspected at least every 6 years, starting at the splash/tidal zones (figure 5-1) and working down. As deterioration is discovered, the level of inspection and frequency needs to be increased accordingly.

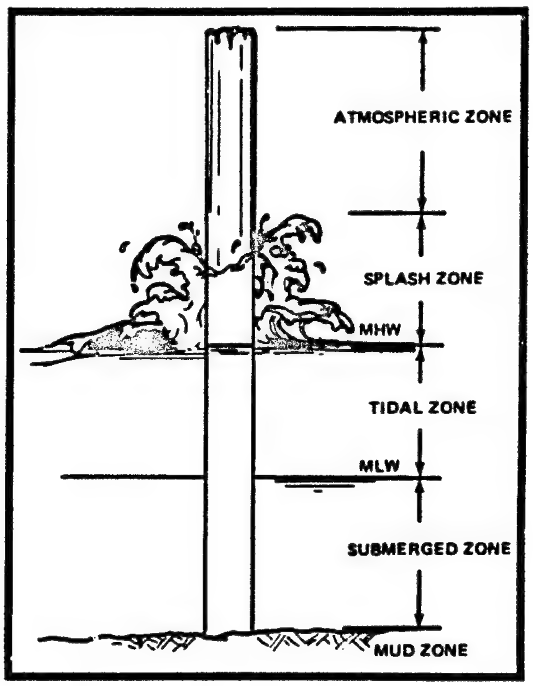


Figure 5-1. Exposure Zones On Piling.

5.1.3.2 Developing the Plan. Prior to starting a facility inspection, all available information about the facility should be obtained. This will include prior maintenance and inspection records, facility drawings, general background information about the existing conditions of the facility, and environmental factors including:

a. Atmospheric temperature range.

b. Water temperature range.

c. Tidal range.

d. Water depths.

e. Water visibility.

f. Currents.

g. Any condition which could have a direct impact on the time required to perform an inspection, such as amount of biofouling growth on piles or any other condition which would inhibit the performance of an inspection such as ice or seasonal flooding. Any other unique features or special problems that may be encountered should also be noted.

A suitable scheme should be devised for designating individual piles and other structural members. The inspection team should use the pile numbering/designation systems available on existing "as-built" drawings where available. Usually, combinations of numbers and letters are used with the number designating the bent and letter indicating the pile within the bent. Legends may be created to represent such things as the degree of deterioration of individual structural members, the level of inspection given to designated portions of a facility, the shape of individual piles, and the type of materials.

Pile plans should be prepared for piers showing the lengths, widths, and spacing of bents. The plans must also include the numbering system used in the inspection and in the report, and these must be correlated with existing drawings of the facility. It is desirable to also include design live load data on all pile plans.

Once the information about the facility and environment has been collected, an inspection plan should be developed. It is important to select a sufficient number of inspection areas to provide representative information on the overall structure. Making this selection requires an understanding of the structure to determine which areas are subjected to maximum stress, fatigue, and impact forces. A knowledge of deterioration and damage theory is also useful. Consequently, the inspection plan must be prepared by a qualified engineer familiar with the structure. The inspection plan should also include the identification of the inspection equipment most appropriate to the specific tasks.

5.1.4 Equipment and Tools

5.1.4.1 Surface Cleaning. To perform a thorough inspection, the marine growth on the structure must be removed. This can be done by various means, depending on surface support. For small sample areas, wire brushes, probes, and scrapers may be adequate. For larger areas or more detailed inspections underwater, a hydraulic grinder with barnacle buster attachment, or high-pressure water jet gun, may be used, exercising care to prevent damage to the preservative-treated layers of timber or deteriorating surfaces of concrete.

5.1.4.2 Inspection. Inspection tools and equipment include:

a. **Hand-held tools** such as portable flashlight, ruler, and tape measure for documenting areas; small or large hammers or pick-axes for performing soundings of the structural member; calipers and scales for determining thicknesses of steel flanges, webs, and plates, or diameters of piling; increment borer and T-handles for extracting core samples from timbers; and chipping tools for prodding the surface of the concrete to determine the depth of deterioration.

b. **Mechanical devices** including a Schmidt test hammer for measuring concrete surface hardness and rotary coring equipment for taking core samples from concrete structures.

c. **Electrical equipment** such as an underwater voltmeter for determining the level of cathodic protection on steel structures and underwater sonic and ultrasonic equipment for detecting voids in timbers or concrete and thickness of structural steel.

Figure 5-2 shows typical equipment applications used in underwater inspections.

5.1.4.3 Recording. Recording tools and equipment are required to provide a complete documentation of the condition of the structure. Simple tools such as clipboard, forms, and cassette recorder for above water inspections, or plexiglass slate and grease pencil for underwater inspection, provide the basic documentation tools. More indepth documentation may be obtained with above water or underwater photography using either colored still-frame cameras or colored video, closed-circuit television. The latter may be very valuable in expediting major underwater inspections. For underwater inspections in turbid water, a clear-water box may be fitted to the lens of the photographic or video equipment to improve visibility between the lens and surface to be inspected.

5.1.5 Documentation of Inspection. For the information to be useful, documentation must be clear and concise and in accordance with generally understood terminology. Inspection forms should be filled out as the inspection progresses, and reports should be completed soon after the inspection has been finished. Standard forms and report formats facilitate the documentation procedure and are essential for comparing the results of the present inspection with past and future inspections. Figure 5-3 is a standard form which may be used for reporting the condition of piles; figure 5-4 is an explanation of the condition ratings for concrete piles used on the form; and figure 5-5 is an explanation of the condition ratings for timber piles. Steel pile inspection results are usually recorded in terms of remaining metal thickness.

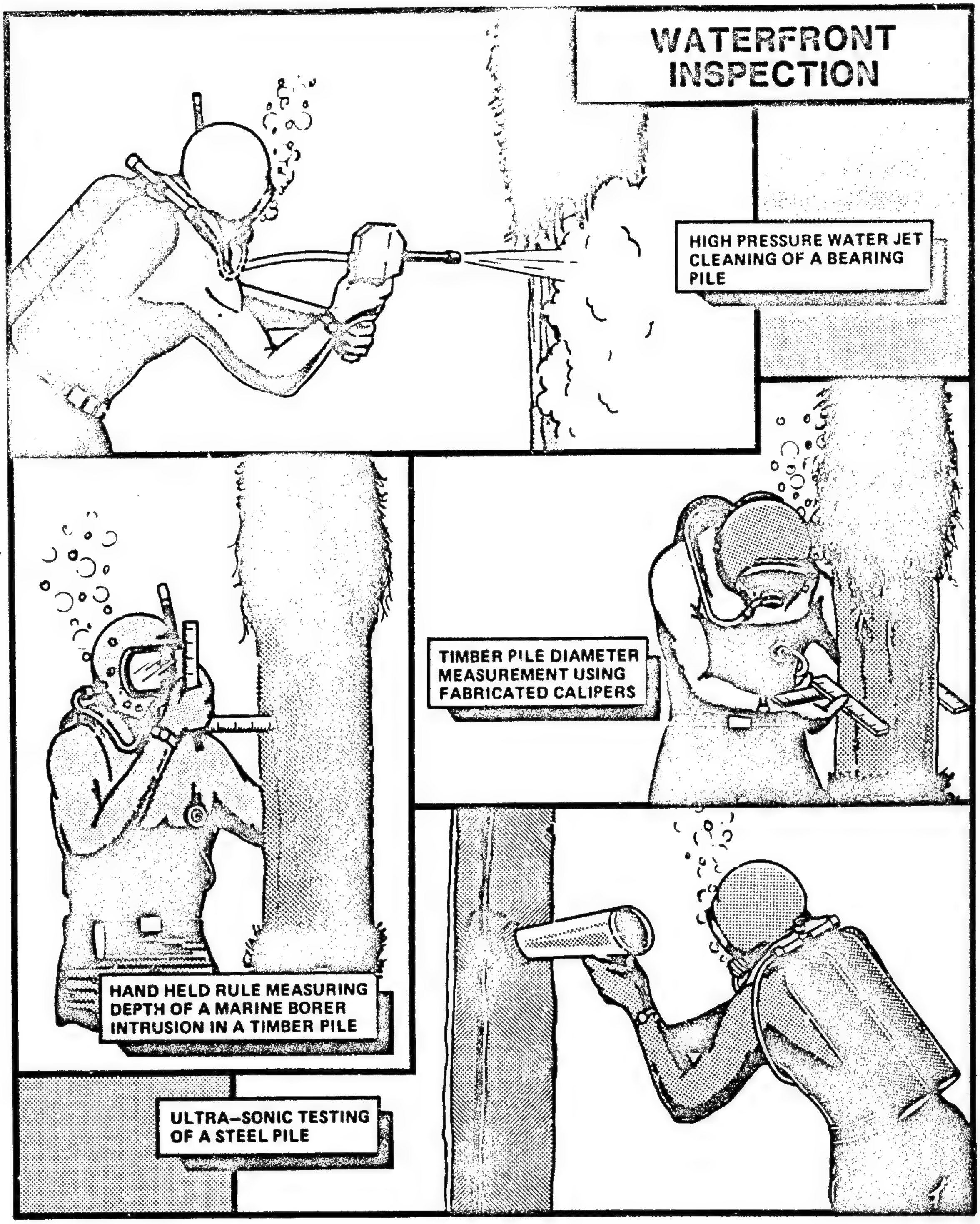


Figure 5-2. Typical Tools and Equipment Used for Waterfront Inspections.

PILE INSPECTION RECORD

LOCATION		DATE	DIVERS			
PIER NAME/NO		PILE TYPE ☐ BEARING	☐ FENDER	☐ SHEET	PILE MATERIAL ☐ TIMBER	☐ STEEL	REINFORCED ☐ CONCRETE
WATER DEPTH	TIME OF DAY	TIDE	DEPTH OF DAMAGE FROM DATUM=GAUGE DEPTH-TIDE			

BENT NO	PILE NO	NI	PILE CONDITION					TYPE DAMAGE			GAUGE DEPTH DAMAGE	DIMENSIONS OF DAMAGE			COMMENTS
			ND	MN	MD	MJ	SV	MECH	BIO	FUNC		HGT	WIDTH	PENETR	

Figure 5-3. Standard Pile Inspection Report Form.

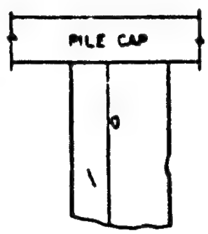
When appropriate, visual inspection should be documented with still photography and closed-circuit television. Still photography provides the necessary high definition required for detailed analysis, while video, although having a less sharp image, provides a continuous view of the inspection. All photographs should be numbered and labeled with a brief description of the subject. A slate or other designation identifying the subject should appear in the photograph. When color photography is used, a color chart should be attached to the slate to indicate color distortions. Video tapes should be provided with a title and lead-in describing what is on the tape. The description should include the method of inspection used, the nature and size of the structure being inspected, and any other pertinent information.

CONCRETE PILES

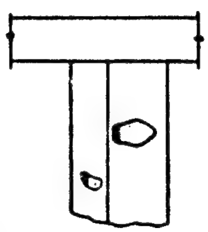
CONCRETE PILE CONDITION RATING	EXPLANATION

NI NOT INSPECTED, INACCESSIBLE OR PASSED BY

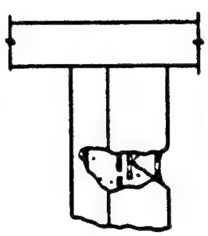
ND NO DEFECTS:
- fine cracks
- good original surface, hard material, sound



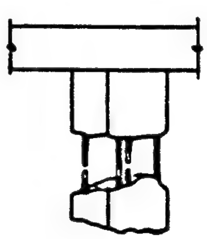
MN MINOR DEFECTS:
- good original section
- minor cracks or pits
- surface spalling that exposes course aggregate
- small chips or popouts due to impact
- slight rust stains
- no exposed re-bar
- hard material, sound



MD MODERATE DEFECTS:
- spalling of concrete
- minor corrosion of exposed re-bar
- rust stains along re-bar with or without visible cracking
- softening of concrete due to chemical attack
- surface disintegration to one inch due to weathering or abrasion
- reinforcing steel ties exposed
- popouts or impact damage



MJ MAJOR DEFECTS:
- loss of concrete (10-15%)
- one or two re-bars badly corroded
- one or two ties badly corroded
- large spalls six inches or more in width or length
- deep wide cracks along re-bar



SV SEVERE DEFECTS:
- two or three re-bars completely corroded
- no remaining structural strength
- significant deformation

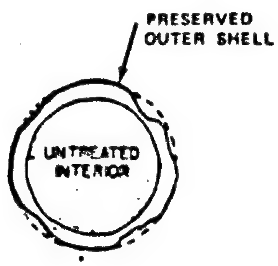
NOTE: Explanation of defect should be placed in the comments column.

Figure 5-4. Pile Condition Ratings for Concrete Piles.

TIMBER PILES

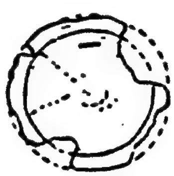
TIMBER PILE CONDITION RATING	EXPLANATION

NI NOT INSPECTED, INACCESSIBLE OR PASSED BY



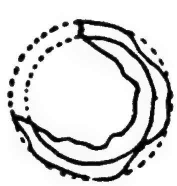
ND NO DEFECTS:
- Less than 5% lost material
- sound surface material
- no evidence of borer damage

MN MINOR DEFECTS:
- 5% to 15% lost material
- sound surface material
- no evidence of borer damage
- minor abrasion damage



MD MODERATE DEFECTS:
- 15% to 45% lost material
- significant loss of outer shell material
- evidence of borer damage
- significant abrasion damage

MJ MAJOR DEFECTS:
- 45% to 75% lost material
- significant loss of outer shell and interior material
- evidence of severe borer damage
- severe abrasion damage



SV SEVERE DEFECTS:
- more than 75% lost material
- no remaining structural strength
- severe borer damage

NOTE: Explanation of defect should be entered in the comments column.

Figure 5-5. Pile Condition Ratings for Timber Piles.

5.1.6 References. Materials used to develop inspection procedures and planning factors outlined in this chapter, have been taken from the following documents:

- NAVFAC MO-322, Inspection of Shore Facilities, Naval Facilities Engineering Command, Washington D.C., July 1977 (reference 2).
- NCEL TM-43-85-01 O&M, UCT Conventional Inspection and Repair Techniques Manual, October 1984 (reference 36).
- CHESNAVFACENGCOM FPO-1-85(26), Guidelines For Preparation of Reports on Underwater Inspections of Waterfront Facilities, December 1985 (reference 37).
- NAVDOCKS MO-306, Corrosion Prevention and Control, Naval Facilities Engineering Command, Washington D.C., June 1964 (reference 38).
- CEL CR 81.009, Survey of Techniques for Underwater Maintenance/ Repair of Waterfront Structures, Childs Engineering Corp., April 1981 (reference 39).

5.2 PERFORMING THE INSPECTION. The procedures that follow cover deck, surface and underwater inspection requirements for:

- Timber Structures
- Concrete Structures
- Steel Structures
- Synthetic Materials and Components
- Rubble-Mound Structures

The basic approach taken in developing the procedures is aimed at identifying potential problems and where they would be expected to be found. Inspection checklists are included, starting with the Level I approach, and proceeding on to more sophisticated Level II and Level III procedures.

5.3 INSPECTION OF TIMBER STRUCTURES

SCOPING THE PROBLEM

The objective of inspecting timber structures is to detect and document:

BY WALKING THE PIER

a. Loose, fractured or missing fender piles, wales and chocks (figure 5-6).

b. Cracked, rotted, loose or worn decking or string pieces, loose hardware, and soft spots in decking (figure 5-6). Include annual load testing of the pier decking if heavy equipment or vehicles are to be driven onto the pier.

BY SURFACE INSPECTION AFLOAT

c. Cracked, fractured, rotted or loose stringers, braces, pile caps, and fire curtain wall planks (figure 5-6); loose bolts; and deflected structural members.

d. Bearing pile deterioration involving fungi and rot damage, marine borer and insect attack, overloading damage, abrasion damage, structural movement cause by corrosion and failure of hardware, and displacement caused by ice heave (figures 5-7 and 5-8).

e. Sheet piling and retaining wall deterioration caused by marine borer and insect attack, abrasive damage, and movement of the timber structure (figure 5-9).

f. Dolphin deterioration including:

(1) Missing, loose, broken or split piles; or signs of abrasions, wear, decay, or marine borer damage in piles.

(2) Poor vertical alignment of dolphin assembly.

(3) Broken, worn, or corroded cables and cable connectors.

(4) Corroded, loose, broken, or missing wedge blocks, chafing strips and bands, or chock bolt hangers.

BY UNDERWATER INSPECTION

g. The extent of bearing pile deterioration in the tidal and submerged zones resulting from marine borer attack, overloading damage, and abrasion damage (figures 5-7 and 5-8). Specific emphasis will be placed on (1) looking for marine borer damage, and (2) documenting changes in pile diameters.

h. The extent of sheet piling and retaining wall deterioration in the tidal and submerged zones, resulting from marine borer attack, abrasive damage, and movement of the structural members (figure 5-9).

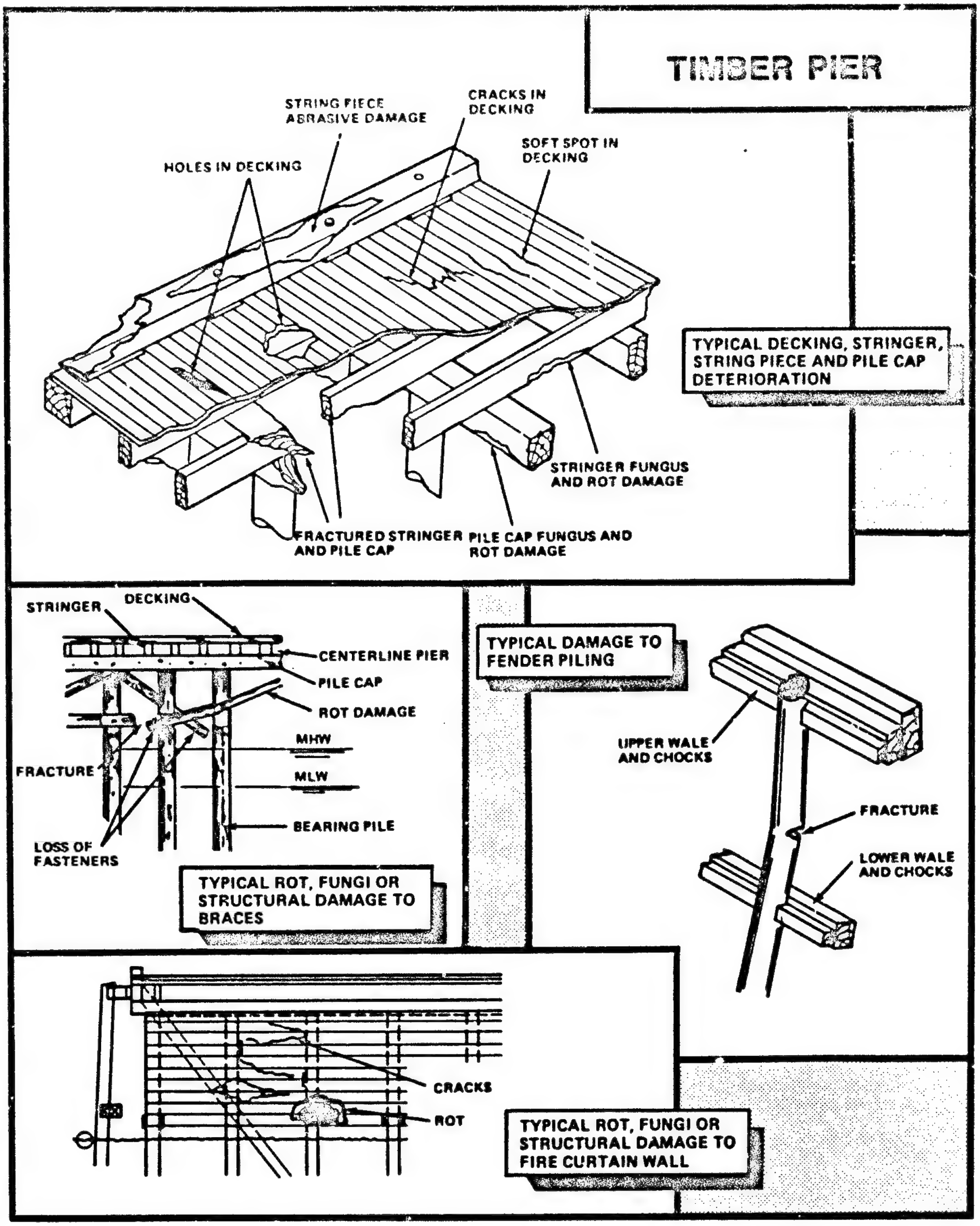


Figure 5-6. Typical Damage Areas Involving Timber Decking, Stringers, Pile Caps, Fire Curtains, and Fender Piling.

While performing the surface and underwater inspections of the pier, wharf, quaywall or dolphin assemblies, the inspector should be alert, specifically in the areas of stringers, pile caps and top of piles, for signs of discoloration and softening of the wood, accompanied by a fluffy or cotton appearance. This may be an early sign of fungi damage. More advanced deterioration may take on the appearance of fruiting bodies, such as mushrooms. Further down the pile, the inspector should look for burrows into the wood, surface trenches in the outer layers of the pile, and loss of pile diameter. This may be evidence of a marine borer attack.

When inspecting above the water surface, the inspector should take maximum advantage of low tide conditions in order to visually observe the overall condition of the piling. This may lead to the determination that an underwater inspection is necessary. The underwater inspection should, on the other HAND, take maximum advantage of high water conditions in order to compile the most comprehensive field data on existing conditions. Table 5-3 summarizes the inspection elements for timber structures.

Table 5-3. Inspection of Timber Structures.

Visual Observations	• Areas of riddled or lost wood • Condition of pile barriers • Diameter/condition of fasteners (bolts, etc), cables, wraps	• Breaking or cracking from Impact or overload • Detection of Limnoria or teredine siphons on surface • Areas of reduction of piling diameter from abrasion or marine borer attach
Special Sampling Equipment	• Increment borer for determining quality of preservative or soundness of piling • Treated wooden plugs for holes left after boring	• Calipers for determining piling diameter • Sonic equipment for detecting hollow areas in piling
Measurement, Ratings, or Samplings	• Piling diameter • Location and size of damaged areas • Depth of cracks and other damaged areas	• Rating of piling condition • Data from sonic equipment • Wood samples or increment borings

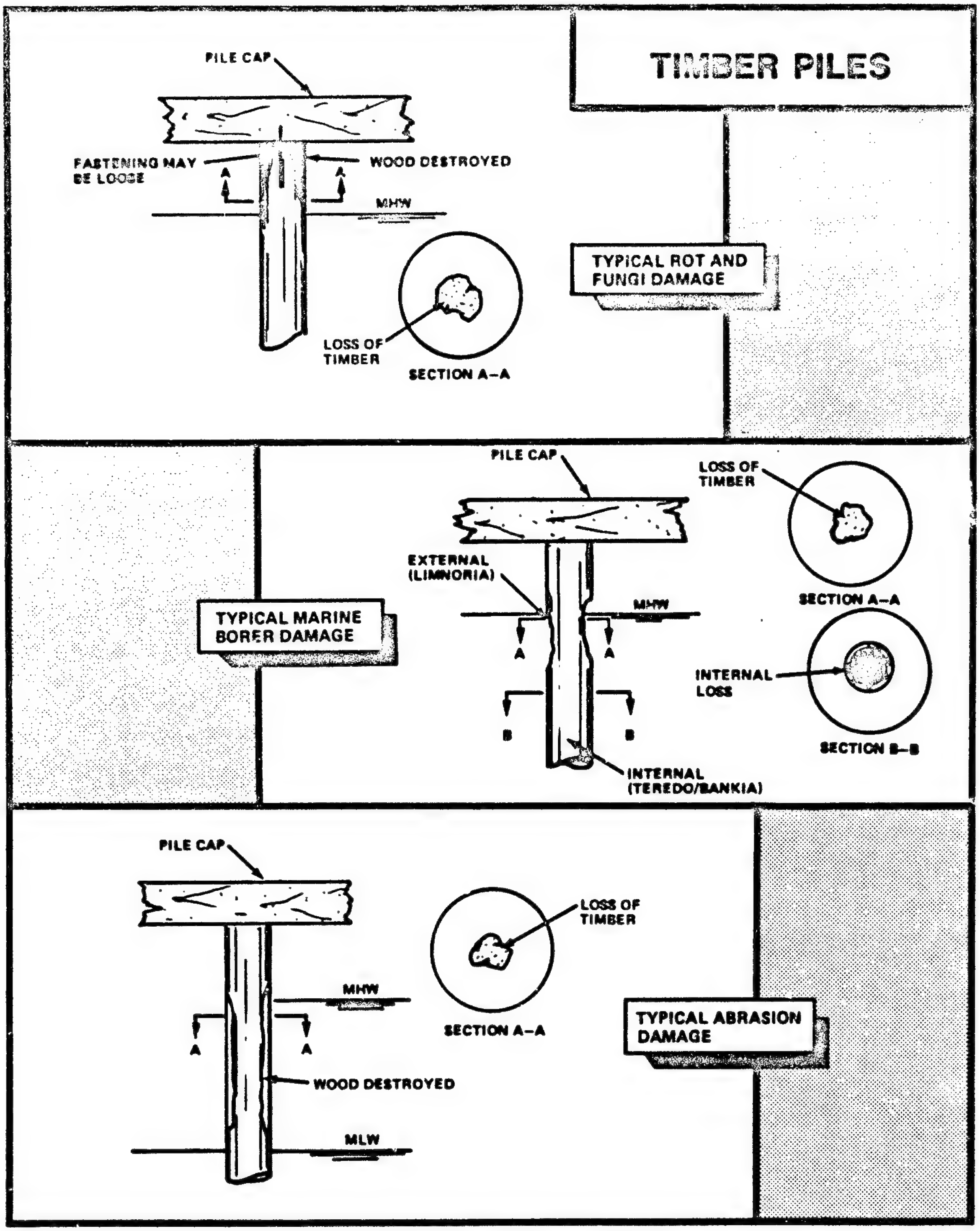


Figure 5-7. Typical Damage to Timber Piles from Fungi and Rot, Marine Borer, and Abrasion.

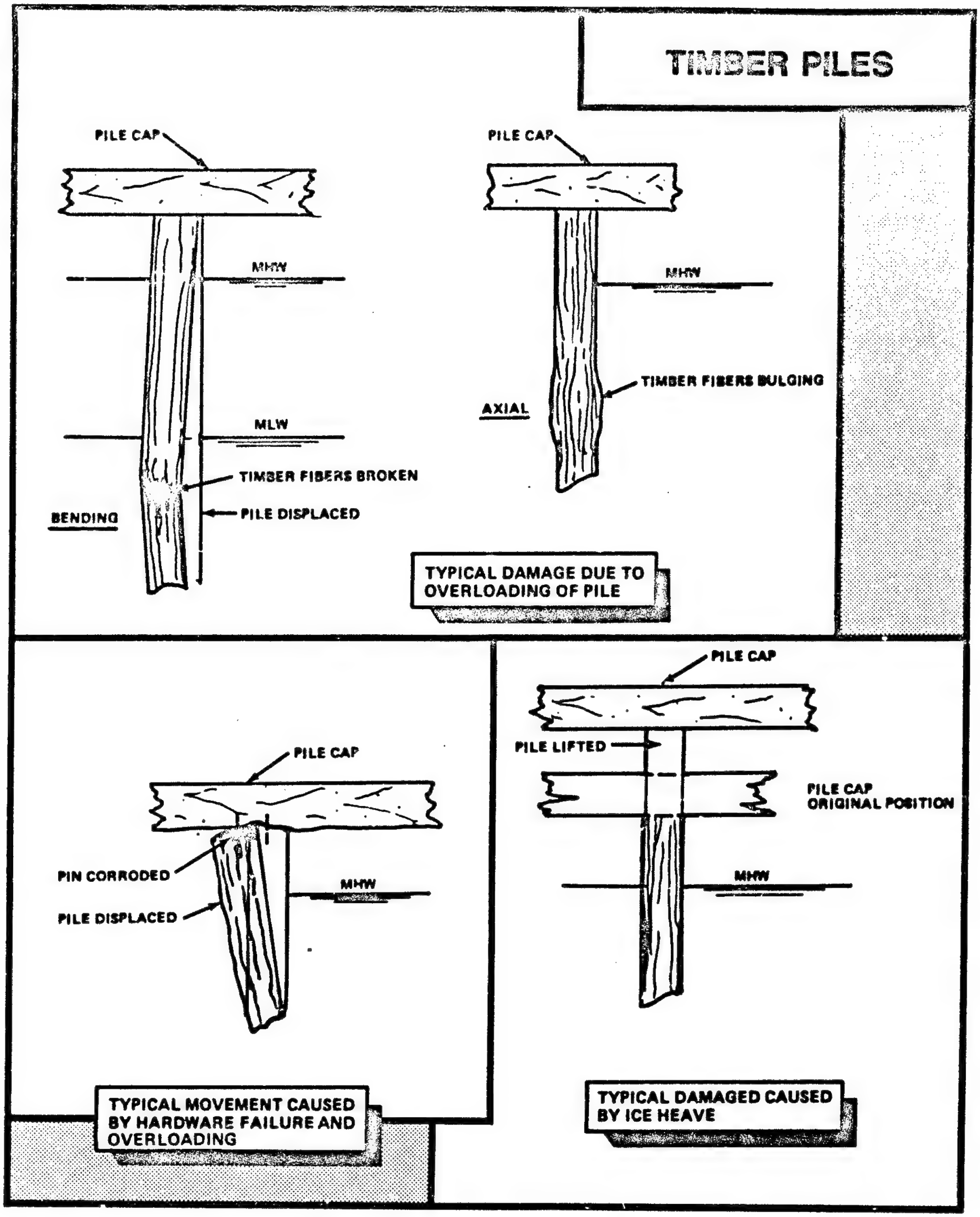


Figure 5-8. Typical Damage to Timber Piles Resulting from Corrosion and Failure of Hardware, Overloading, and Ice Heave.

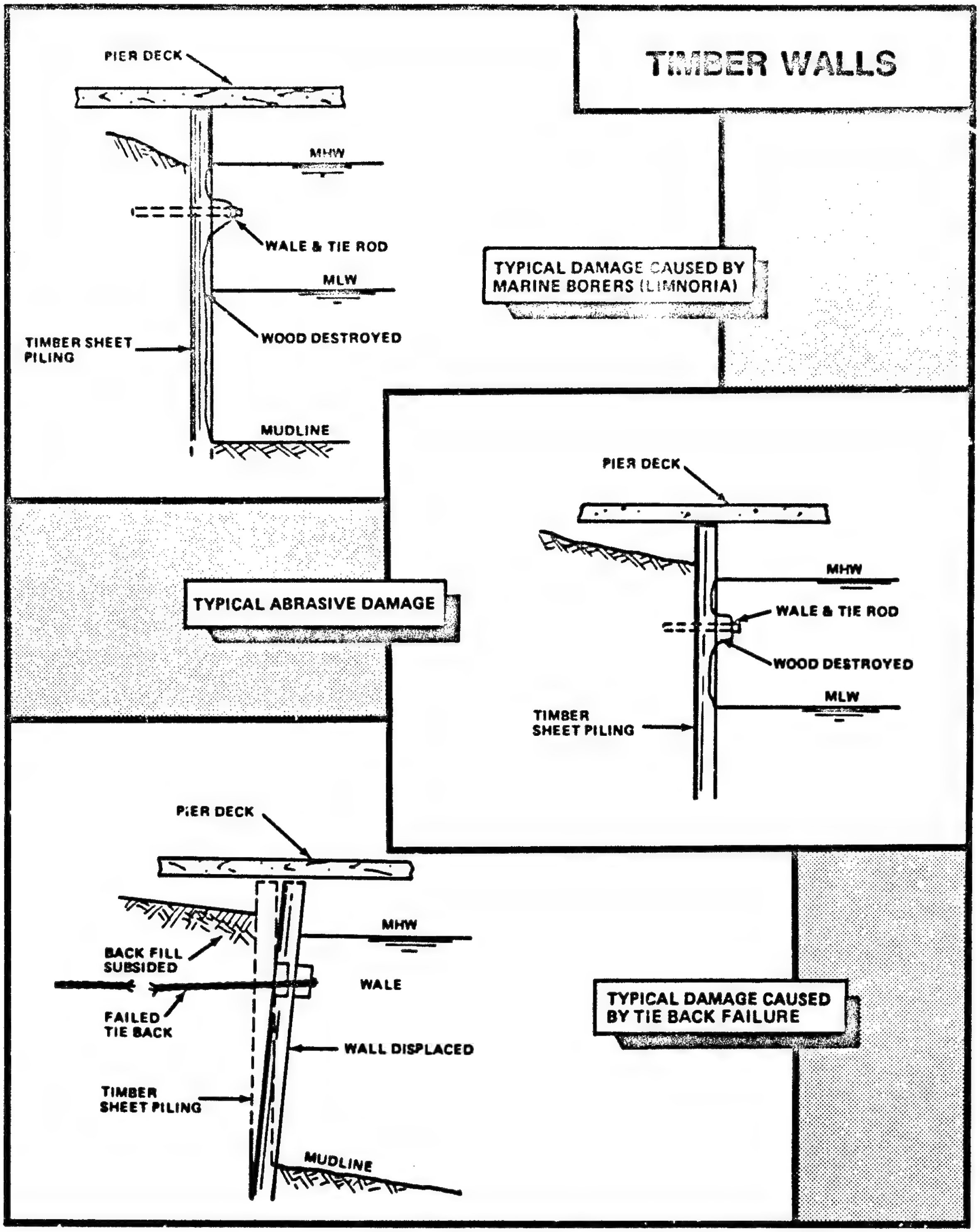


Figure 5-9. Typical Damage to Timber Sheet Piling from Marine Borer Attack, Abrasion Damage, or Tie-Back Failure.

5.3.1 Surface Inspection Procedures.

TIMBER STRUCTURE SURFACE INSPECTION CHECKLIST	
Checkpoint	Description
MAIN DECK AREA OF PIER OR WHARF	
1.	Check horizontal and vertical alignment.
2.	Check for missing, broken or loose connections, obstructions and other hazardous conditions of curbings, handrails and catwalks.
3.	Check bollards, bits, cleats and capstans for wear, breaks, rough or sharp surfaces or edges and missing or loose bolts.
4.	Check deck drains and scuppers for loose, missing or broken screws, water ponding and other deficiencies.
5.	Check manhole covers and grating for rust, corrosion, bent or worn hinge pins, and other damage.
6.	Inspect asphalt deck coverings for cracks, holes, and other damage (if applicable).
7.	Check ladders and deck planking for rust and corrosion, broken, bent or missing rungs, and rot, termite or pest infestations.
8.	Check grounding connections for tightness.
EXPOSED AREA UNDER PIER OR ALONG WHARF OR DOLPHIN ASSEMBLY	
9.	Check wood stringers, pile caps, bearing, batter and fender piles, for missing or broken members. Check dolphins for broken, worn or corroded cables and cable connectors; and corroded, loose, broken or missing wedge block, chafing strips and bands, or chock bolt hangers.
10.	Visually examine piling for rot, fungi, and marine borer damage.
11.	Sound the pile areas with a hammer and carefully probe with a thin-pointed tool such as an icepick.
12.	If an area is in question, take a small boring for laboratory analysis using an increment borer. Once the core is extracted, seal the hole with a creosote treated plug to prevent easy access of borers to the interior of the pile.

5.3.2 Underwater Inspection Procedures.

TIMBER STRUCTURE UNDERWATER INSPECTION CHECKLIST	
Checkpoint	Description
1.	Start at the splash/tidal zones. Note: A Level I inspection should be conducted first to identify areas of mechanical damage, repair, and new construction.
2.	Clear a section of the structure of all marine growth and visually inspect it for surface deterioration. This is usually done at spot locations rather than cleaning entire structure.
3.	Sound the cleaned area with a hammer and carefully probe with a thin-pointed tool such as an icepick.
4.	If an area is in question, take a small boring for laboratory analysis using an increment borer. Place a creosote treated plug in the hole to prevent easy access for marine borer entry.
5.	Descend down the pile, sounding the structure with a hammer wherever there is minimal marine growth, as well as probing carefully with an icepick.
6.	At the bottom, note and record the depth of the water on a plexiglass slate with a grease pencil.
7.	Record visual observations such as presence of marine borers, losses of cross-sectional area, organism-caused deterioration, location and extent of damage, alignment problems, and condition of fastenings. Use calipers and scales as required.
8.	Where internal damage from marine borers is suspected, ultrasonic techniques are available to support the underwater inspection program. The ultrasonic equipment is only available as a contractor service at this time.
9.	Upon finishing the underwater work, return to the surface and immediately record all observation data into the inspection log. Similar procedures would be followed for timber retaining walls.
	NOTES:
	An engineer should be present whenever underwater inspections are made to explain to the diver exactly what should be looked for: number and size of piles, type and depth of bulkheads, location of tiebacks, and cross bracing. The engineer shall evaluate the diver's observations and determine the degree-of-hazard.

5.4 INSPECTION OF CONCRETE STRUCTURES.

SCOPING THE PROBLEM

The primary method of inspecting concrete is by visual observation. Most durability problems will be detected visually using only simple hand tools such as pick and hammer; only after problems are detected should other inspection methods be considered. These other methods may include using probe, coring or sonic test equipment.

The basic objective of the inspection is to detect and document:

BY WALKING THE PIER

a. Cracking, chipping, spalling and general disintegration of pier decking and curbs, utility trenches, and utility gallery areas; cracked or loose joint sealers; exposure and corrosion of reinforcing steel; and loose or corroded hardware (figure 5-10). Areas where the inspector should be particularly watchful for signs of deterioration, include:

- Inside corners and areas where radical changes occur in size of sections.
- Expansion joints where insufficient gap is allowed, rigid joints between precast units, and construction joints in general.
- Poorly designed scuppers, drips, and curb slots, and other areas where inadequate drainage exists.

BY SURFACE INSPECTION AFLOAT

b. Cracking, chipping, spalling, exposing of reinforcing steel, efflorescence, and general disintegration of the underside of pier decking and pile caps (figure 5-10).

c. Shrinkage, swelling and chemical deterioration; freeze/thaw deterioration; abrasion wear; and overload damage of piles (figure 5-11).

Areas where the inspector should be particularly watchful for signs of deterioration include: joints between the deck and pile cap, expansion joints where insufficient gap is allowed, and rigid joints between precast piles and cast-in-place pile caps.

d. Cracking, chipping, spalling and general disintegration of seawalls resulting from chemical deterioration; freeze/thaw deterioration and abrasion wear of concrete surfaces; and loosening of bolted steel or timber fender system.

BY UNDERWATER INSPECTION

e. The extent of bearing pile or seawall deterioration in the tidal or submerged zones, resulting from shrinkage, swelling and chemical deterioration; freeze/thaw deterioration; abrasion wear; and/or overload damages.

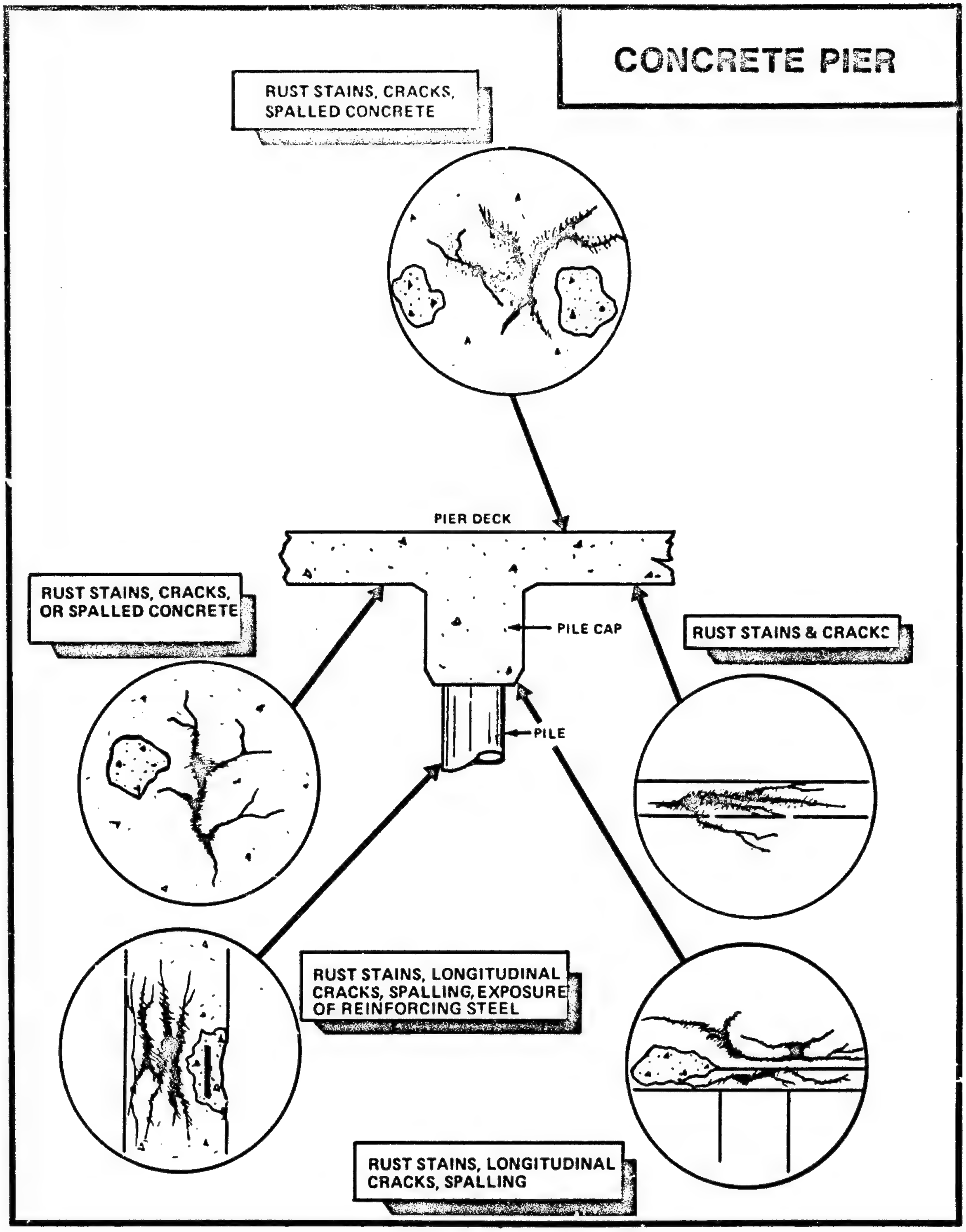


Figure 5-10. Typical Inspection Areas for Visual Indications of Concrete and Reinforcement Deterioration.

During inspection, the inspector should be alert for any change in appearance of the concrete surface and any change in sound from the hammer. Chemical attack will be indicated by erosion of surface material or by cracking on the surface. Freeze-thaw deterioration will appear as erosion of surface material. A hammer or gad (sharp pointed tool), should be used to chip or probe the surface to detect the depth of deterioration.

Corrosion of reinforcement can be detected from rust stains on the surface. More advanced stages of corrosion will be evident by cracks that run parallel to the steel reinforcing bars. At times, corrosion is hidden from view, but will be indicated by a hollow sound from the hammer. This can occur on heavily reinforced slabs, such as pier decks, where the reinforcement has corroded enough to spall a layer of concrete at the level of the reinforcing mat.

Cracks found on the surface of a concrete structure should be given careful attention. Sketches should be made to show the length and direction of the cracks. Measurements of the length of cracks should be made. Overall cracking patterns and changes in crack length, width and direction with time are meaningful data to a structural engineer. The causes of the cracks need to be determined. Photographs are helpful, but only as a supplement to the sketches.

If there is evidence of significant deterioration, more detailed NDT techniques may be employed in a scheduled Level III inspection. The plan and sampling techniques shall be tailored to the specific areas of concern.

Table 5-4 summarizes the inspection elements for concrete structures.

Table 5-4. Inspection of Concrete Structures.

Visual Observations	• Chipping, cracking, spalling and disintergration • Rust spots • Bottom scouring, undermining	• Condition of exposed steel • Joint conditions
Special Sampling Equipment	• Hammer equipment • Chipping tool • Concrete-core rotary drilling equipment	• Sonic or ultrasonic • Power source
Measurements, Ratings of Samplings	• Location and size of damaged area • Depth of chips, cracks spalls, etc.	• Drilled concrete cores • Sonic or ultrasonic data

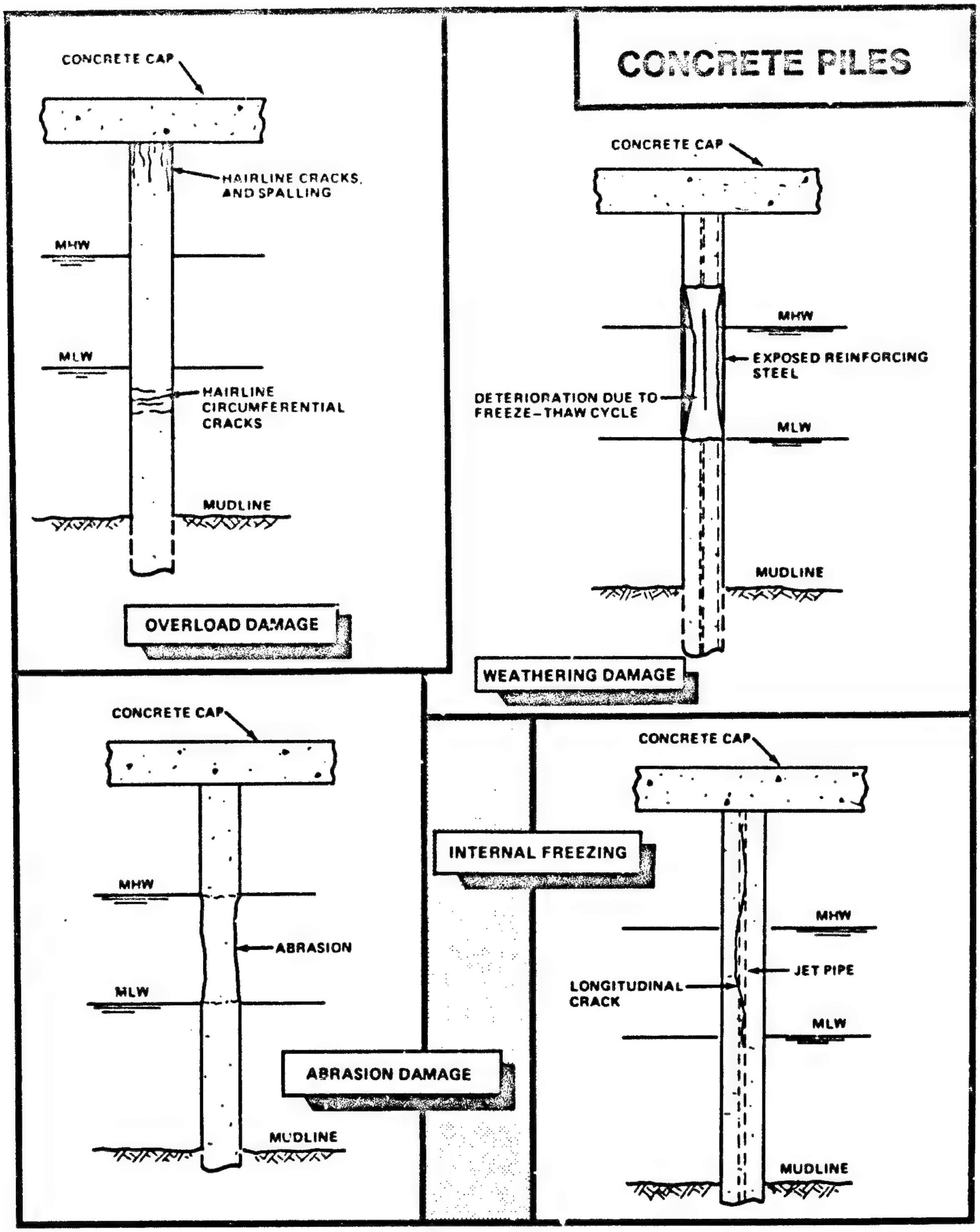


Figure 5-11. Typical Damage to Concrete Piles from Weathering, Freezing, Abrasion, and Overloading.

5.4.1 Surface Inspection Procedures.

CONCRETE STRUCTURE SURFACE INSPECTION CHECKLIST	
Checkpoint	Description
MAIN DECK AREA OF PIER OR WHARF	
1.	Check horizontal and vertical alignment.
2.	Check for missing, broken or loose connections, obstructions and other hazardous conditions of curbings, handrails and catwalks.
3.	Check bollards, bits, cleats, and capstans for wear, breaks, rough or sharp surfaces or edges, and missing or loose bolts.
4.	Check deck drains and scuppers for loose, missing or broken screws, water ponding, and other deficiencies.
5.	Check manhole covers and grating for rust, corrosion, bent or worn hinge pins, and other damage.
6.	Inspect concrete deck surface and curbs for cracks, spalling and other damage. Closely inspect for visual signs of rust.
7.	Check ladders for corrosion, and broken, bent or missing rungs.
8.	Check grounding connections for security.
EXPOSED AREA UNDER PIER OR ALONG WHARF OR DOLPHIN ASSEMBLY	
9.	Check pile caps and bearing, batter and fender piles for damaged or broken members, cracks and spalling of concrete, rust stains, and exposed reinforcing steel.
10.	Sound the piling or structure with a hammer to detect any loose layers of concrete or hollow spots. A sharp ringing noise indicates sound concrete. A soft surface will be detected, not only by a sound change, but also by a change in the rebound, or feel, of the hammer. A thud or hollow sound indicates a delaminated layer of concrete, most likely from corrosion of steel reinforcement. NOTE: If signs of deterioration or damage are found, then a Level III inspection, involving either nondestructive or destructive tests may be required. Refer to the Level III Test Procedures for Concrete Inspection for mechanical and electrical test methods.

5.4.2 Underwater Inspection Procedures.

CONCRETE STRUCTURE UNDERWATER INSPECTION CHECKLIST	
Checkpoint	Description
1.	Inspect the structure beginning in the splash/tidal zone. This is where most mechanical and biological damage is normally found.
2.	Clear a section about 18 to 24 inches in length of all marine growth.
3.	Visually inspect this area for cracks with rust stain, broken pieces caused by spalling or mechanical damage, and exposed reinforcing steel.
4.	Sound the cleaned area with a hammer to detect any loose layers of concrete or hollow spots in the pile or structure. A sharp ringing noise indicates sound concrete. A soft surface will be detected, not only by a sound change, but also by a change in the rebound, or feel, of the hammer. A thud or hollow sound indicates a delaminated layer of concrete, most likely from corrosion of steel reinforcement.
5.	Descend, visually inspecting the pile or structure where marine growth is minimal, and sound with a hammer.
6.	Inspect in greater detail the base of mass concrete structures, such as retaining walls and foundations. These types of structures are prone to undermining by wave and current action which, if not rectified, could lead to failure of the structure.
7.	At the bottom, record the water depth along with any observations of damage on a plexiglass slate.
8.	Upon return to the surface, immediately record all information into the inspection log.
	If signs of deterioration or damage are found, then a Level III inspection, involving either nondestructive or destructive tests, may be required. Refer to the Level III Test Procedures for Concrete Inspection for mechanical and electrical test methods.

5.4.3 Level III Test Procedures for Concrete Inspection.

CONCRETE STRUCTURE
LEVEL III INSPECTION TECHNIQUES

Technique	Description

MECHANICAL METHODS

1. The Schmidt test hammer may be used in order to compare the relative surface quality of concrete at different locations on the same structure. The hammer works on the same principal as tapping the concrete with a hand-held hammer. The instrument measures the hardness of concrete surfaces by the extent of rebound of a spring-loaded steel plunger in a tubular frame. The relative surface quality of the concrete, which is also an indication of its compressive strength, can be obtained.

The following test methods are destructive in nature and should be used only if other techniques cannot be employed.

2. Core samples may be taken from selected areas in order to determine the cause and depth of deterioration, the chemical content, particularly chlorides, within the concrete, and the actual compressive strength. Special care should be taken when setting up to drill a core, in order to avoid hitting steel reinforcement, especially prestressed steel. Steel reinforcement near the surface can be located by use of a pachometer. The length of the core sample should be at least one-half the thickness of the concrete member. Following coring, the hole should be patched using an approved epoxy grout.

3. The Windsor probe may be used to fairly accurately determine the inplace concrete compressive strength at the surface . A hardened steel projectile is shot into the concrete surface. The depth of penetration of the projectile is correlated to the concrete strength. The type of aggregate used in the concrete must be known for proper correlation.

4. The pullout test is another method for determination of concrete strength at the surface. Special shaped holes are drilled in concrete, into which inserts are installed and then pulled out. The force to pull the insert out is an indication of concrete strength. The method is not as standardized as the Windsor probe test, but it is a valid method of good accuracy.

Prior to initiation of the tests, a test plan must be prepared and the areas to be tested must be cleaned thoroughly.

CONCRETE STRUCTURE
LEVEL III INSPECTION TECHNIQUES (Continued)

Technique	Description
	ELECTRICAL METHODS
5.	Sonic and ultrasonic methods are available to inspect concrete for voids that cannot be seen, such as honeycomb pockets, and for internal deterioration by cracking. Pulse velocities and fundamental frequencies are imposed in the concrete structure to search for imperfections. Sonic methods conducted at specific time intervals can monitor progressive deterioration.
6.	If reinforcing steel is found exposed, an electrical method, called the copper sulfate half-cell test, can be used to determine the extent of active corrosion and the degree of susceptibility of corrosion in other areas in the structure. Corrosion can be detected before visible signs appear. The method detects corrosion by measuring current flow through the concrete-steel system. An electrical connection is made from one side of a voltmeter to an embedded steel reinforcing bar that has been exposed. The other side of the voltmeter is connected to a copper sulfate half cell, which is then put in contact with the concrete surface at various locations. The magnitude and sign of the resulting voltage is an indication of corrosion activity.

5.5 INSPECTION OF STEEL STRUCTURES.

SCOPING THE PROBLEM

There are six major types of steel structure deterioration to be watchful for in the marine environment: (1) corrosion, (2) abrasion, (3) loosening of structural connections, (4) fatigue, (5) overloading, and (6) loss of foundation material.

Corrosion may be evident during visual inspection in H-piles and sheet piling in two areas, the splash zone and approximately 2 feet below mean low water (figure 5-12). Inside steel pipe piling, anaerobic bacterial corrosion caused by sulphate-reducing bacteria may also be found to exist (figure 5-12). This type of corrosion is especially difficult to detect by visual inspection.

Abrasion of steel structures can generally be recognized by a worn, smooth, polished appearance.

Loosening of structural connections may be evidenced by misalignment of mating surfaces and by looseness or distortion of structural member.

Fatigue distress can be recognized by a series of small hairline fractures perpendicular to the line of stress in the member. Fatigue cracks are difficult to locate by visual inspection. This type of problem is more prevalent to offshore platforms with welded structural connections than to standard piers and wharves.

Overloading may be visually evidenced by: (1) deformation or distortion of a structural member in the form of a sharp crimp, or compression of a bearing or batter pile (figure 5-13), or (2) deflection of steel sheet piling, as caused by failure of tie-backs or excessive overload of backfill (or live load) (figure 5-13).

Loss of foundation material generally will involve scour of materials from around the piles supporting the structural element (figure 5-13) as typically caused by overdredging. A loss of foundation material in front of a sheet pile bulkhead may cause kickout of the toe of the wall and result in total failure.

Cathodic protection systems need to be closely monitored both visually and electrically for signs of loss of anodes, wear of anodes, disconnected wires, damaged anode suspension systems, and/or low voltage.

Generally, visual inspections will allow detection and documentation of most forms of deterioration of steel structures. In the event that more detailed NDT techniques may be required under a Level III inspection, a plan and sampling techniques need to be developed and tailored to the specific areas of concern.

Table 5-5 summarizes the inspection elements for steel structures.

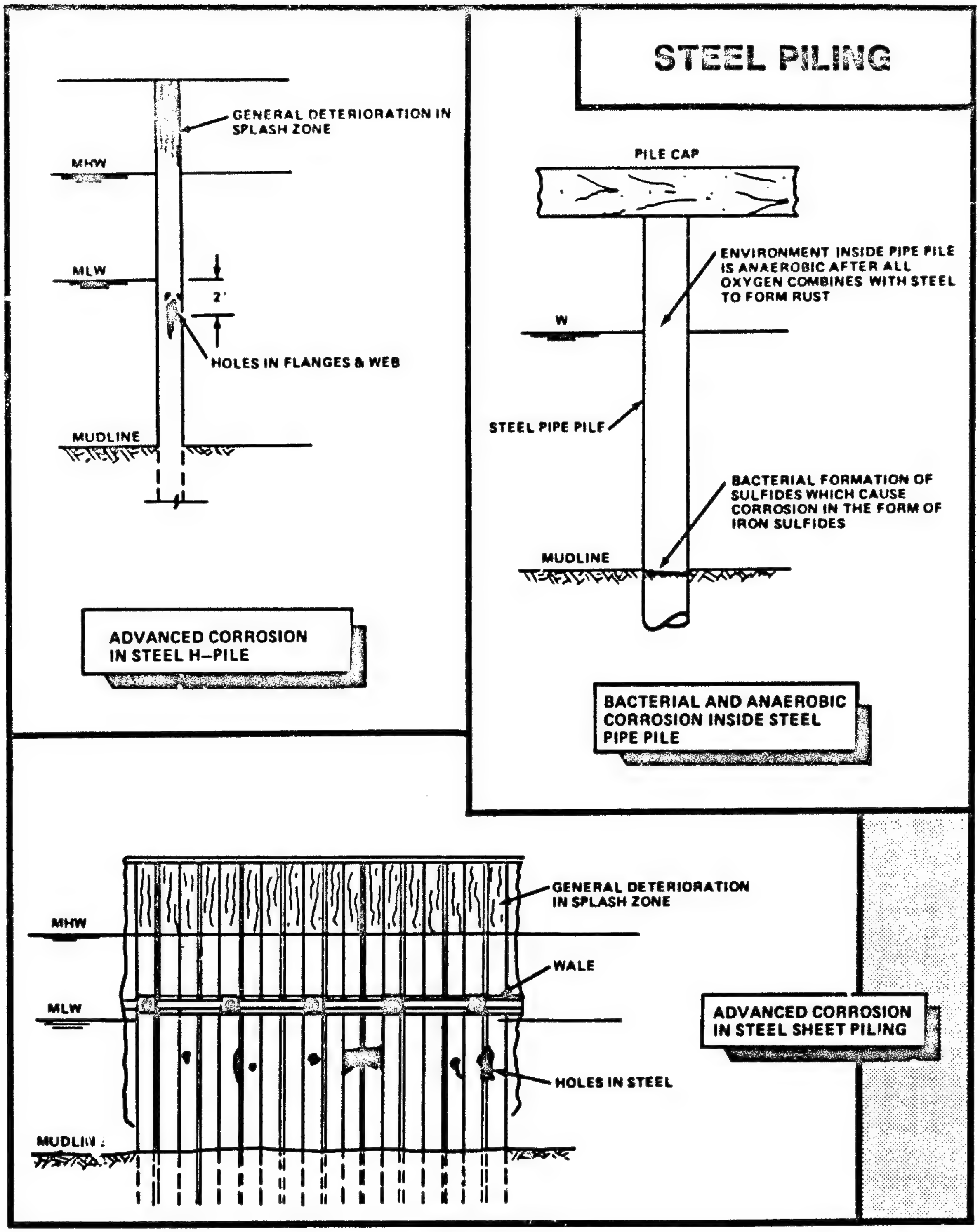


Figure 5-12. Typical Corrosion Damage to Steel Bearing and Sheet Piling.

Table 5-5. Inspection of Steel Structures.

Visual Observation	• Coating condition (peeling), blistering, erosion, etc.) • Condition of cathodic protection equipment (broken or corroded conduits, loose wires, lost anodes, etc.) • Extent of corrosion • Type of corrosion (density pitting, etc.)	• Members structurally damaged by impact • Open seams or holes in quaywalls, etc. • Soil subsidence because of lost backfill through seams or holes • Inspection of welds
Special Sampling Equipment	• Scale or calipers for determining thickness • Ultrasonic equipment for determining thickness • Voltmeter and half-cell for measuring electric potentials on cathodically protected steel	• Pit gage • Equipment for patching holes cut into steel structures • Power source
Measurements, Rating or Samplings	• Metal thickness • Location and size of damaged areas • Depth of pits and extent of their occurrence	• Samples of corrosion products or damaged coatings • Cathodic protection potentials • Deformation of structural members

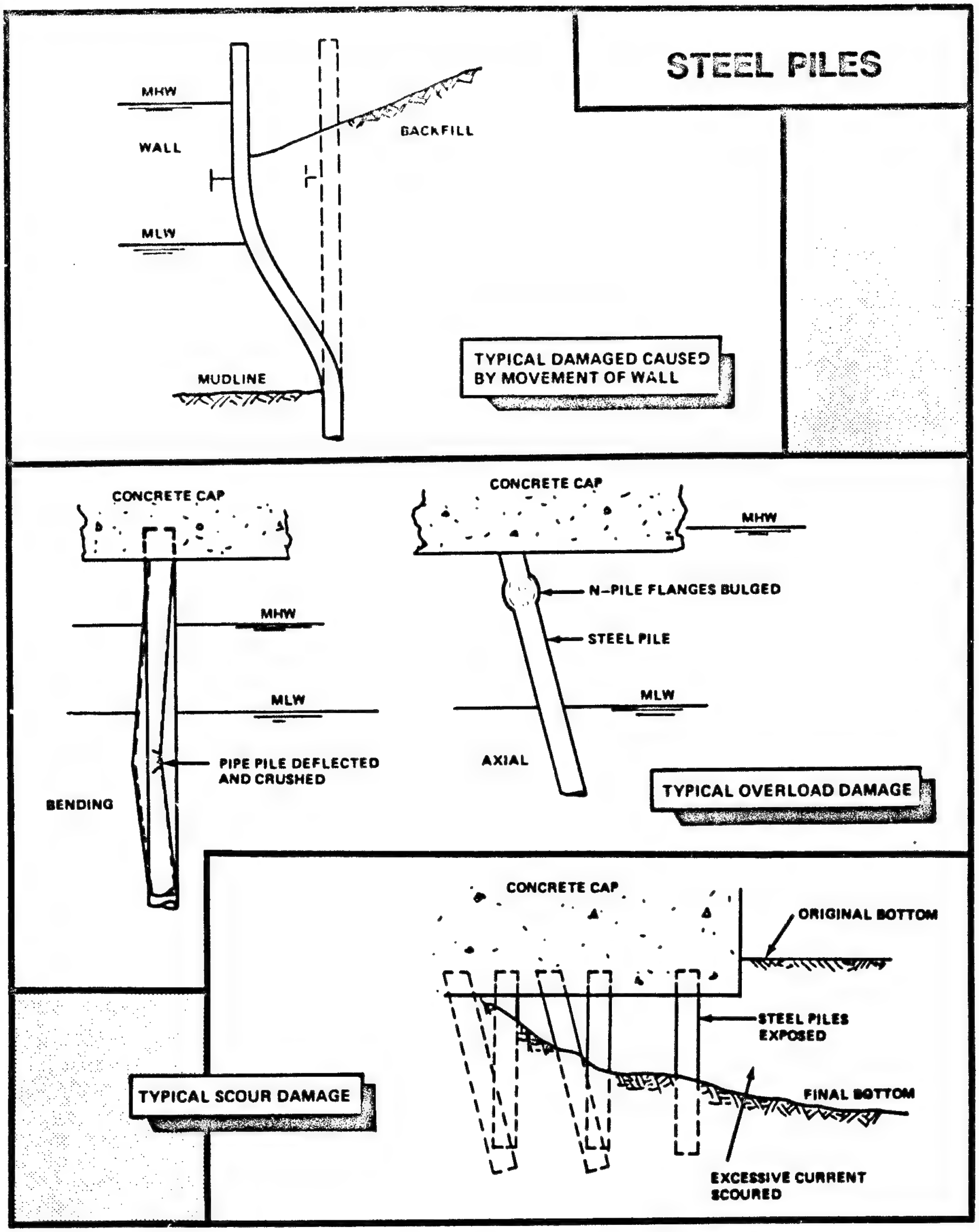


Figure 5-13. Typical Damage to Steel Bearing and Sheet Piles From Overloading, Wall Movement or Scour.

5.5.1 Surface Inspection Procedures.

STEEL STRUCTURES SURFACE INSPECTION CHECKLIST	
Checkpoint	Description
MAIN DECK AREA OF PIER OR WHARF	
	Refer to either Timber Structures or Concrete Structures Surface Inspection Checklist. depending upon type construction.
EXPOSED AREA UNDER PIER OR ALONG WHARF	
1.	Inspect for structural damage, rust, scale and holes.
2.	Sound the surface with a hammer to detect any scaled steel or hollow areas.
3.	Inspect holes in steel sheeting for loss of backfill material through the opening and subsidence of adjacent ground surface.

5.5.2 Underwater Inspection Procedures.

STEEL STRUCTURES UNDERWATER INSPECTION CHECKLIST	
Checkpoint	Description
1.	Start the inspection at the splash/tidal zones and at a depth of about 2 feet below MLW. This is where most mechanical and corro sion damage is normally found.
2.	Clean all marine growth from a 1-foot square section of pile (a larger area, if inspecting sheeting) and visually inspect for rust, scale, and holes.
3.	If the structure has a cathodic protection system, check the cleared area with an underwater voltmeter to determine its effec tiveness. Acceptable levels of cathodic protection are between -0.80 to -0.90 volt when compared to a silver/silver chloride reference cell.
4.	Sound the surface with a hammer to detect any scaled steel or hollow areas.

STEEL STRUCTURES SURFACE INSPECTION CHECKLIST (Continued)	
Checkpoint	Description
5.	Inspect holes in steel sheeting for loss of backfill material through the opening and subsidence of adjacent ground surface.
6.	Descend, visually inspecting the structure and sounding with a hammer where there is minimal marine growth.
7.	At the bottom, record the water depth, using a wrist depth gauge, on a plexiglass slate with a grease pencil.
8.	Record other visual observations, such as coating condition (peeling, blistering, erosion). Closely inspect splices for loss of weld materials and looseness of splices.
9.	Record the condition of cathodic protection equipment (broken or corroded conduits, loose wires, consumed or lost anodes).
10.	Record the extent and type of corrosion, structural damage, or any other significant observations, using calipers and scales to determine thickness of steel flanges, webs and plates.
11.	Return to the surface and immediately record the observation data in the inspection log.
12.	Where more sophisticated means are required to evaluate the condition of steel piling: • Ultrasonic inspection is available for more complete thickness measurements. Particular attention must be taken to ensure that the areas are clear of all marine growth and scale. Use of ultrasonic equipment in areas with corrosion pitting can result in erroneous thickness measurements. • Magnetic particle inspection may be used, particularly on welded connections, to detect cracks and small defects.

5.6 INSPECTION OF SYNTHETIC MATERIALS AND COMPONENTS.

SCOPING THE PROBLEM

Inspection of synthetic materials and components is subdivided into three categories: structural members; coatings, patches and jackets; and buoyancy materials such as foam-filled fenders.

a. **Structural Members.** Structural members should be inspected annually when the regular pier inspection is accomplished. The inspection is intended to detect and document:

(1) Cracked, worn, brittle or deformed plastic railings, stancheons, gratings, light standards, or piping; loose or damaged fittings and connections; and exposed fiberglass.

(2) Cracked, worn, or deformed rubber resilient fender components, and/or loose or damaged fittings and connections.

Basic inspection procedures are the same as those outlined for timber or concrete structures.

b. **Coatings, Patches and Jackets.** Coatings, patches, and jackets should be inspected annually, or more frequently, depending upon the failure rate of the application. The objective of the inspection is to detect and document:

(1) Pits, cracks, scars or abrasions in coatings.

(2) Cracked, loose or dislodged epoxy patches.

(3) Punctures, brittleness, tears, rips, or abrasions in fabric, or unlocking of fabric seams in pile jackets.

Basic inspection procedures are the same as those outlined for timber, concrete and steel structures.

c. **Foam-Filled Fenders.** Inspection of foam-filled fenders should be performed more frequently than normal pier inspections and should cover:

(1) Condition of the fender-to-pier connection hardware. Check for operability and signs of corrosion. Check to ensure that the fender is constrained horizontally so that it contacts the bearing surface for its full length. Ensure that the fender is free to float with the tide vertically and rotate around its long axis.

(2) Condition of the fender chain and tire net for net fenders. Check to see that the chain is symmetrical on the fender and that the end fittings are in good working order. Ensure that the chains are protected from the ship hull by the tires, and that the net is not loose.

(3) Condition of end fittings on netless fenders. Check to see that the fittings are in good working order, and corrosion is minimal. Check to see that the fender shell is not cracked or separated around end fittings.

(4) Condition of the fender elastomer shell. Check for cuts, tears, and punctures. Record the size and location of damage on a sketch.

(5) Measure or estimate the diameter of the fender at its smallest point to record permanent set.

Inspection will be done by walking the pier and by use of a small boat.

Recordkeeping for foam-filled fenders is very important. In this regard, the fenders should be treated as an item of high-cost equipment rather than an appurtenance to a fixed facility. Each fender should have a unique identification number with a history record that includes date of procurement, manufacturer, date of installation or when fender was put into service, and berth location if permanently installed.

5.7 INSPECTION OF RUBBLE-MOUND STRUCTURES.

SCOPING THE PROBLEM

The four principal types of deterioration in rubble mound waterfront structures are: sloughing of side slope, slippage of base material as a result of scour by currents, dislodgement of stones by wave action, and excessive settlement of the seabed supporting the structure.

During the inspection of seawalls, breakwaters, groins and jetties, similar to those shown in figure 5-14, the inspector should check for horizontal and vertical alignment. He should also be particularly watchful for signs of breakage or displacement of large stones or concrete armor elements, and washing out of substrate under the larger stones or concrete elements, particularly at the toe of the structure. These losses can be early signs of eminent structural failures if corrective action is not taken.

Other points to check may include curbing, handrails and catwalks (as applicable) for loose, missing or broken sections, obstructions, and other hazardous conditions.

Table 5-6 summarizes the inspection elements for rubble-mound structures.

Table 5-6. Inspection of Rubble Mound Structures.

Special Sampling Equipment	Visual Observation	Measurements, Rating or Samplings
None required.	Erosion of core material by wave action. Erosion of small stones in riprap. Stability of armor stones or blocks. Breakage and displacement of concrete armor elements. Washing out of substrate at the toe of structures. Undermining of foundation. High water mark; overtopping. Settling of structures.	Location and size of damaged areas. Slope of structure.

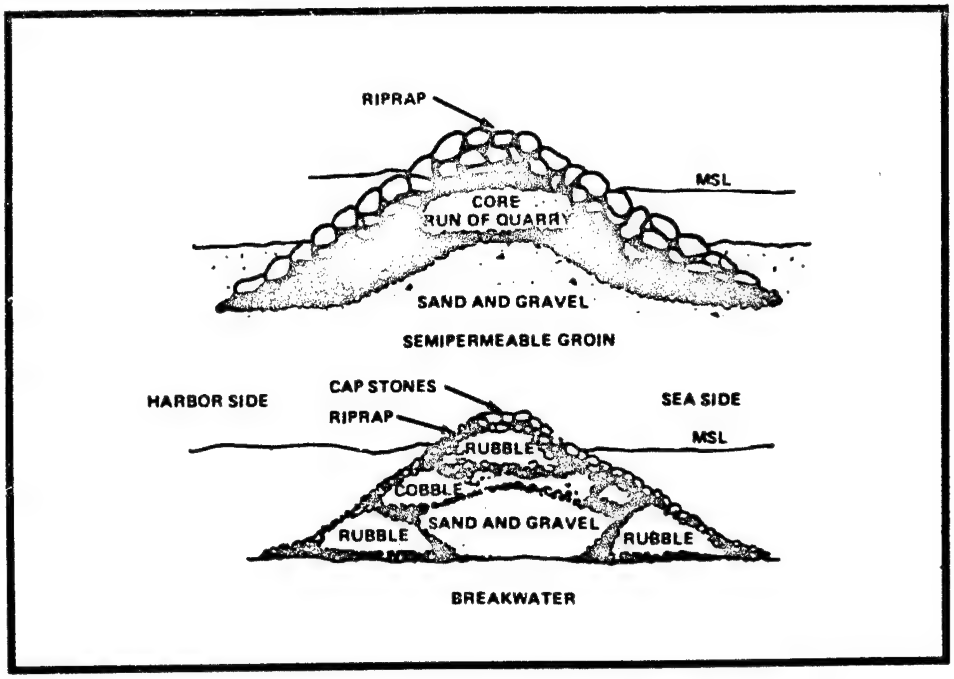


Figure 5-14. Typical Rubble-Mound Structures.

5.7.1 Rubble-Mound Inspection Procedures.

RUBBLE-MOUND STRUCTURES SURFACE AND UNDERWATER INSPECTION CHECKLIST	
Checkpoint	Description
1.	Swim around the base of the structure looking for beginning weaknesses in the base of these structure, such as washout of small stones and core material.
2.	Note signs of detrimental wave action, such as scouring and sloughing.
3.	Record all pertinent information on a plexiglass slate and, upon return to the surface, transfer the information into the inspection log.
4.	Record the result of the above water inspection, which should include a description of the alignment, and general condition of the mound, such as dislodgement of stones, gaps, and other weaknesses.

CHAPTER 6. REPAIR OF WOOD AND TIMBER STRUCTURES

6.1 GENERAL. The most common uses of wood and timber structures in waterfront facilities involve:

- Older piers, wharves, bulkheads, and quaywalls constructed from dimension lumber, beams and stringers, and round timber piles.
- Fender systems constructed from beams and stringers and round timber piles.
- Pile dolphins constructed from round timber piles.
- Log floats and camels, beams and stringers, dimension lumber, glued and laminated wood, and miscellaneous forms.
- Degaussing facilities that require the use of nonmagnetic construction materials.
- Groins constructed from beams and stringers and round timber piles.

With the exception of fender systems, floats and camels, most systems have been installed for several decades, in many cases dating back to World War II.

The need to conduct an effective repair program for these facilities is essential if continued usage of the facilities is planned and if escalating costs of repairs are to be avoided. Postponing the repairs, particularly for bearing piles, can lead to costly replacement or downgrading of the structural capacity of the facility.

Repair methods for wood and timber structures are generally directed at correcting one or more of the following problem areas: fungi and/or insect attack, marine borer deterioration, abrasion, and overload.

The selection of repair method to be used must consider the following elements:

- Facility mission and required life.
- Extent of damage and deterioration.
- Estimated life expectancy with and without repairs.
- Projected load capacities.
- Problems associated with mobilization of equipment, personnel, and material to accomplish repairs/maintenance.
- Economic trade-offs.

6.2 REFERENCES. Materials used to develop repair techniques and planning factors outlined in this chapter have been taken, in part, from the following documents:

- NCEL TM-43-85-01 O&M, UCT Conventional Inspection and Repair Techniques Manual, October 1984 (reference 36)

- CEL CR 81.009, Survey of Techniques for Underwater Maintenance/Repair of Waterfront Structures, Childs Engineering Corp., April 1981 (reference 39)

6.3 PLANNING THE REPAIRS. Accomplishment of repairs to timber structures will frequently be controlled by the availability of skilled personnel and equipment. In many cases, structural repairs, particularly involving bearing piles and sheet piling, will be accomplished by contract.

The initial planning step to determining the repair approach must involve review of prior inspection reports in order to determine the scope of damage and/or deterioration, the rate of deterioration, and specific operational constraints placed upon the facilities because of the deterioration. Once the scope of repair requirements, including priorities, are established, the method of accomplishment, whether in-house or by contract, must be determined.

6.3.1 Special Skill Requirements. Surface type repairs covering pier decking, string pieces, stringers, pile caps, braces and fender piles require skills common to the wharf building trade. Underwater repairs, however, require special skill levels that may not be available within in-house forces. These include knowledge of removal of marine growth, jetting or air lifting procedures, underwater cutting and drilling techniques, and jacketing and wrapping materials used in underwater construction.

6.3.2 Equipment Requirements. Surface type repairs to the pier superstructure and fender system will generally require equipment common to in-house shop forces. Equipment for underwater repairs, however, may include: high-pressure water blaster, hydraulic grinders with barnacle buster attachment, hydraulic drill with bits, hydraulic power unit, hydraulic chain saw, concrete pump with hosing, jetting pump and hose, rigging equipment, float stage and scaffolding, clamping template for cutting piles, special clamping equipment, and crane.

6.4 REPAIR PROCEDURES. Repair procedures for waterfront wood and timber structures are summarized in table 6-1. Usage of any of the repair techniques which follow should fully adhere to the preservation treatment requirements outlined for wood and timber structures in chapter 3.

Every effort should be made in rafting and handling to prevent damage to treated piles and timbers, particularly in portions of the work exposed to marine borer attack. Care should also be taken in driving piles to prevent checking or splitting of the treated wood, and butts shall be trimmed and headed so that the hammer will strike only untreated wood. Piles and timbers should be inspected before and during the time they are driven or placed. Where the protective preservative shell is broken or damaged in any way, the holes and/or crevices should be repaired by drilling, and neatly and tightly plugged in accordance with AWPA Standard M4. Where abrasions or other damages cannot be sealed against marine borers, other protection must be provided in an approved manner. All piles shall be handled in accordance with AWPA Standard M4.

Table 6-1. Repair Techniques for Wood and Timber Structures.

NO.	DESCRIPTION
Pier Superstructures and Fender Systems	
TR-1	Repairing Timber Pier Superstructure
TR-2	Repairing Timber Fender Pile
Bearing Piles	
TR-3	Protecting Timber Piles with Polyvinyl Chloride Wrapping
TR-4	Partial Posting of Damaged Pile with New Pile Butt
TR-5	Posting of Damaged Pile with New Pile Butt Post
TR-6	Repair Timber Piles with Concrete Encasement
TR-7	Replacing Damaged Pile with New Timber Pile Under Timber Pier Deck
TR-8	Replacing Damaged Pile with New Concrete Pile Under Concrete Deck
Timber Sheet Piling Walls	
TR-9	Patching Small Holes in Timber Sheet Piling
TR-10	Patching Large Holes in Timber Sheet Piling
TR-11	Reinforcing Tie-Back System For Timber Sheet Piling Wall
TR-12	Installing a Tie-Back System on the Top of a Timber Sheet Piling Wall
TR-13	Installing a Concrete Cap/Face on a Timber Sheet Piling Wall
Dolphins	
TR-14	Repair of Dolphins

TR-1: REPAIRING TIMBER PIER SUPERSTRUCTURE

Decking. Decking should be replaced with properly treated quarter-sawn timber when its top surface becomes excessively uneven, hazardous, or worn to a point of possible failure. Spacing between decking planks is normally provided for ventilation and drainage. Decking for relieving platforms which have an earth fill should be laid in a double layer without spacing between planks.

Pile Caps. Decayed or damaged pile caps should be replaced with treated members Replacement caps should be the same size and length as the original caps unless redesigned.

Braces. Diagonal braces that have been broken or attacked by fungi or marine borers should be replaced rather than spliced. Braces should be located well above high water and all bolt holes should be treated with a preservative. Where braces are fastened to a piling, the pile should not be cut or dapped to obtain a flush fit. Where decking has been removed for repairs, it is often possible to drive diagonal brace piles to provide lateral stiffness. This procedure eliminates all bolt holes except those at the top of the structure immediately below the decking.

Stringers. Decayed or damaged short stringers should be replaced with properly treated members. Decayed or damaged areas of long stringers should be removed and replaced with properly treated new sections. Connections between replacement and existing stringers should be made directly over a pile cap and stringers should be bolted tightly or pinned to the pile cap (figure 6-1). Splices in adjacent stringers should be staggered where possible.

String Pieces. String pieces are subjected to much wear and alternate wetting and drying. Properly treated replacement sections should be long enough to reach a minimum of two bents. New preservative-treated blocks, 2 to 3 inches thick, should be placed under each upper string piece replacement section at intervals of 3 to 4 feet to provide for drainage (figure 6-1). The entire lower string piece should be replaced if any part of the timber has deteriorated.

Fire Curtain Walls. Wood fire curtain walls are usually made of two layers of planking which run diagonally to one another. All deteriorated planks should be replaced to restore the wall to its original condition - as watertight as possible. Also, each side of the wall should be protected by automatic sprinklers or by nearby openings in the deck through which revolving nozzles or other devices can be used to form an effective water curtain.

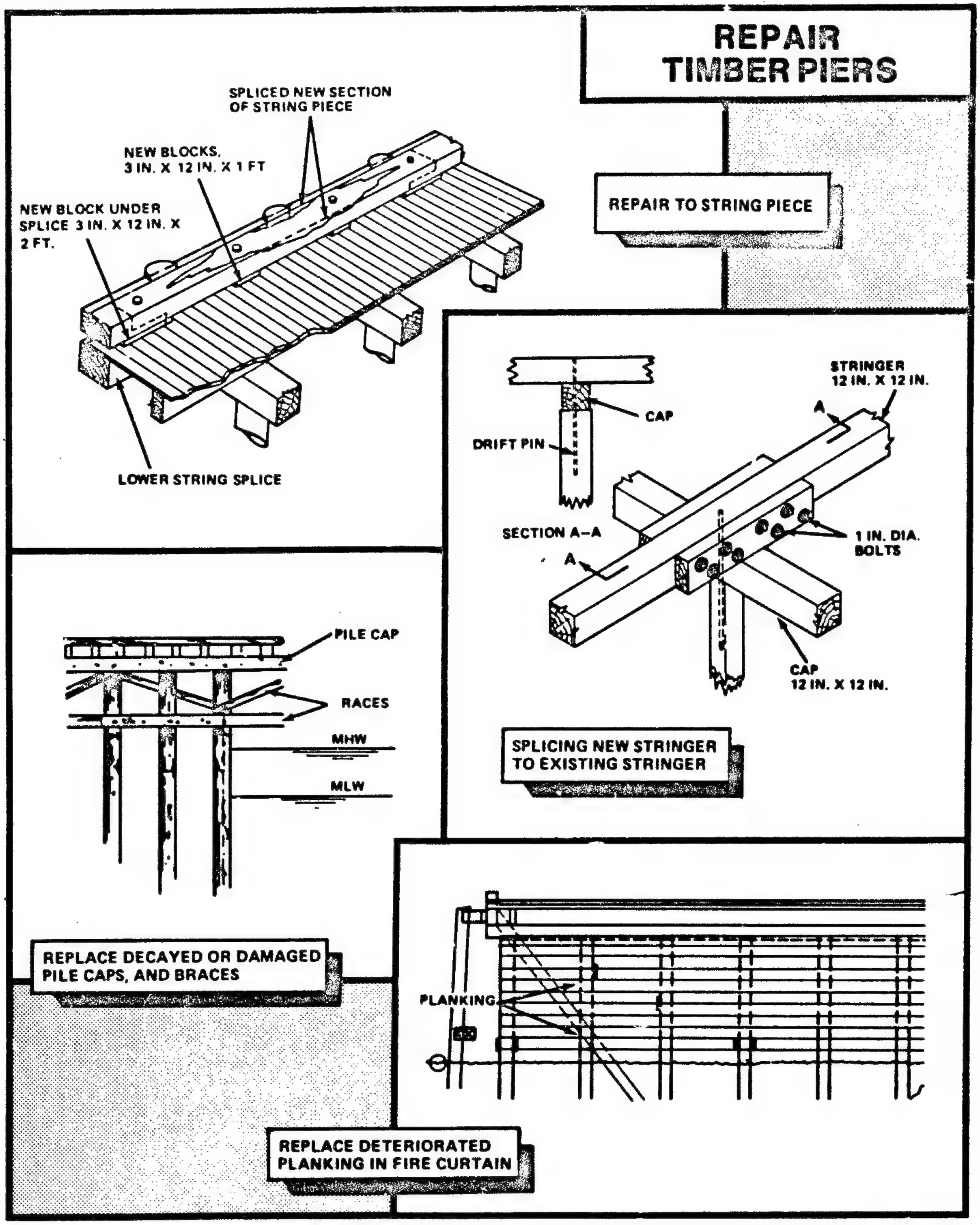


Figure 6-1. Repairs to Timber Pier Superstructure Involving Decking, Pile Caps, Braces, Stringers, String Pieces and Fire Curtain Walls.

TR-2: REPAIRING TIMBER FENDER PILE

Problem: Fender pile broken between upper and lower wale. Lower portion of pile basically maintains original alignment.

Description of Repair: Cut off pile just below the break. Install a new section of pile and secure with epoxy cement (figure 6-2). Fit and bolt a strongback pile or timber section in place directly behind the fender pile and between the top and bottom wales. Attach a metal shoe (wearing strip) to the wearing edge of each fender pile. The level of treatment to be applied to the fender piles will be determined at the activity level based on estimated life expectancy of the pile. Larger piles (18-inch diameter) or pile clusters should be treated for preservation against marine borers, fungus and insects.

Decayed, marine borer damaged, or broken fender piles that cannot be adequately repaired should be pulled and replaced with new piles. Installation of a steel shoe on the outer surface of each fender pile is recommended.

Deteriorated chocks should be replaced with tightly fitting chocks that are bolted to one string piece or to a wale below the deck. Treatment requirements will be locally determined.

Deteriorated or damaged wales should be replaced with the same size and length as the original wales unless redesigned. Treatment requirements for the wales will be locally determined.

Application: The method of repair by sectional replacement is generally limited to piers berthing tugs, barges, etc. where damage is sparodic and infrequent, making mobilization of a full wharf building crew uneconomical.

Future Inspection Requirement: The inspection frequency should be based upon historical records of fender pile damage.

REPAIR TIMBER FENDER PILE

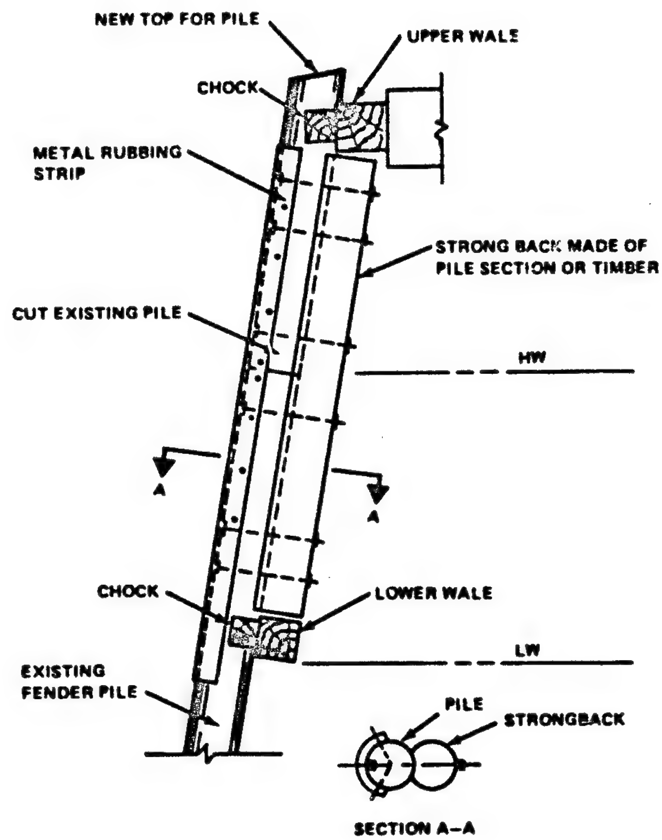


Figure 6-2. Repair by Splicing Timber Fender Pile.

TR-3: PROTECTING TIMBER PILES WITH POLYVINYL CHLORIDE WRAPPING

Problem: Either a new pile or pile butt is being installed which requires a protective covering, or minor to moderate marine borer (less than 30 percent) deterioration has been discovered in an existing pile, and further damage needs to be prevented.

Description of Repairs: Clean the surface of the pile to be protected to remove all sharp or protruding objects which would penetrate or cause undue deformation of plastic wrapping of pile.

> **Single-Unit Timber Pile Wrap:** Wrap a 4-mil polyethylene sheet around the pile to protect the PVC wrap, if fresh creosote is on the pile. Wrap the PVC jacket, of proper width and length, around the pile to below the mudline; start closing zipper from the top. Install top strap to secure jacket in place. Close zipper and install straps down to bottom (figure 6-3).
>
> **Multi-Unit Timber Pile Wrap:** If pile is new and creosoted, wrap first with a polyethylene liner. Install the PVC wrap starting with the upper intertidal unit at least 1 foot above MHW. The lower unsealed units then overlap the upper units and extend below the mudline. The PVC wrap is tightened using wood poles and a ratchet wrench. The wrapper is fastened with aluminum alloy bands around the top and bottom and with aluminum alloy nails along the vertical joints (figure 6-3).

Following completion of the wrap, the area around the base of the pile is backfilled.

Application: This method is widely used for preventing or arresting marine borer attack. More economical than concrete encasement or pile repair/replacement. In addition, a 150-mil polyethylene wrap in the intertidal area can provide abrasion protection.

Future Inspection Requirement: Special attention is required during inspection to look for punctures in the PVC wrap.

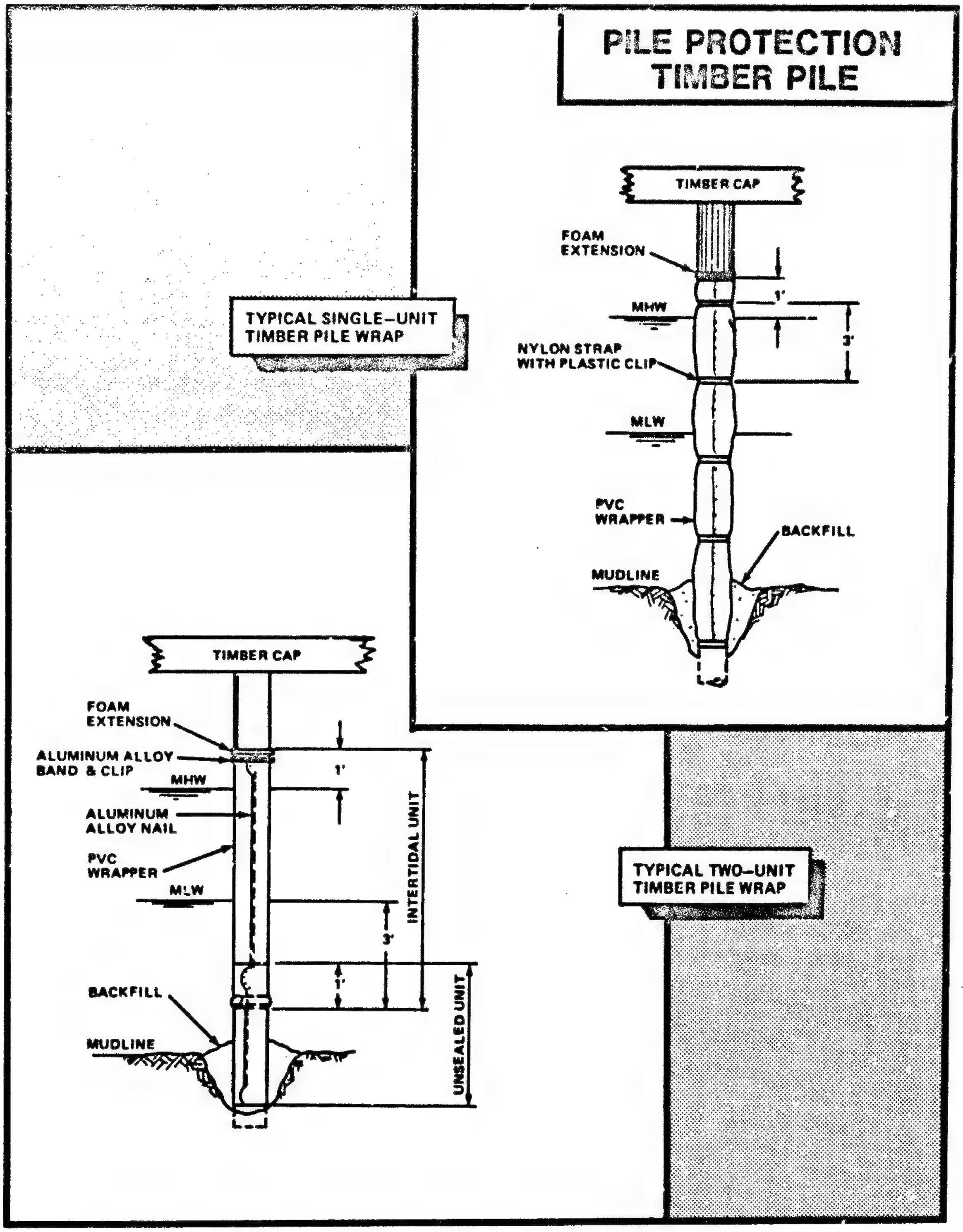


Figure 6-3. Wrapping Timber Piles with Polyvinyl Chloride to Protect from Marine Borers.

TR-4: PARTIAL POSTING OF DAMAGED PILE WITH NEW PILE BUTT

Problem: Top of pile has rotted or experienced major insect damage. No other major detectable deterioration of piling found.

Description of Repairs: Cut the pile below the damaged, rot, or insect infested area. Cut the pile butt to length and shape the head to fit the pile cap (if required). See figure 6-4 for two methods of interfacing pile butt with pile cap. Make the joint with two pretreated timber fish plates bolted to existing pile and pile butt using 1-inch galvanized bolts. Treat the ends of all cuts with creosote. Treat bolt holes with the same wood preservative as used for the pile butt. Shim between the new pile butt head and pile cap. Bolt the pile, or fish plates, depending upon the method selected, to the pile cap.

When adjacent timber piles have been repaired using either posting or fish plating techniques, it is often necessary to provide some resistance to lateral loads imposed on the structure. This can be accomplished by installing X-bracing between piles, as illustrated in figure 6-4. Treated timbers are fastened high on one pile and low on the adjacent pile, forming an X pattern. Where the X-bracing crosses, a timber spacer should be bolted between the bracing pieces to shorten the unsupported length of span.

Application: This method works well where not many piles need repair. It is less expensive than cutting pile at mudline.

Future Inspection Requirement: Even with X-bracing, weak joints will exist where column buckling may occur. All splices and holes below Mean High Water (MHW) may be subject to accelerated marine borer attack. This may be partially offset by the addition of a PVC wrap around the splice.

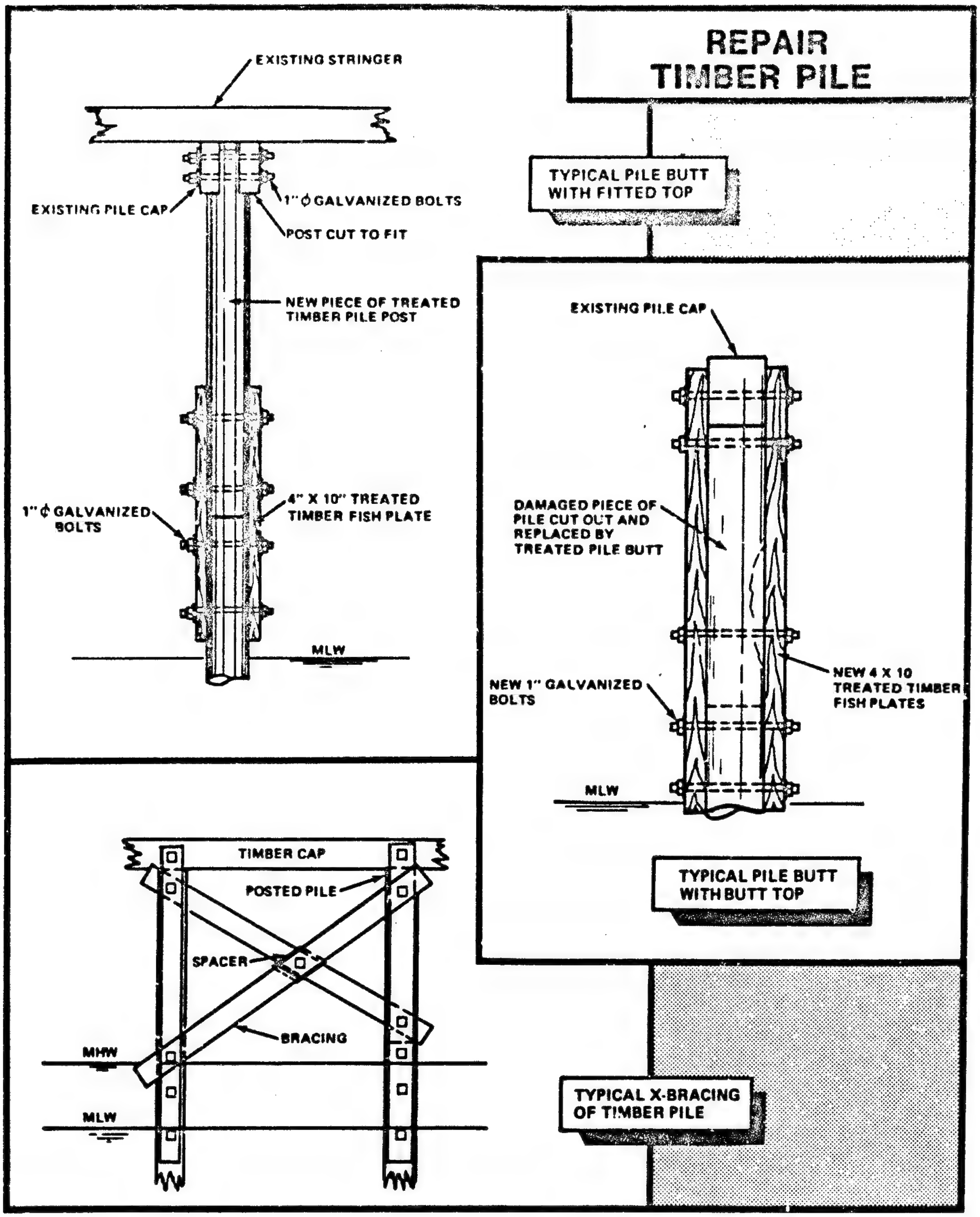


Figure 6-4. Posting Timber Pile with Pile Butt and Fish Plates.

TR-5: POSTING OF DAMAGED PILE WITH NEW PILE BUTT POST

Problem: Entire pile down to mudline has experienced severe deterioration.

Description of Repairs: Cut the damaged pile below the mudline at sound wood. Cut the new pile butt post to length and shape the head to fit the pile cap (if required). See figure 6-5 for two methods of interfacing pile butt post with pile cap. Three methods are available for mounting the pile butt post:

> **For Dowel Method,** drive the steel dowel into the piece of pile remaining in the ground. Bore the hole for the dowel in the pile butt (usually 1/16-inch undersized). Place the pile butt over dowel and maneuver into place.
>
> **For Drift Pins,** bore slightly undersized holes for the drift pins into the new pile butt section and maneuver the section into place. Galvanized steel drift pins are then driven into the part of pile remaining in the seabed.
>
> **For Pipe Sleeve,** a pipe or split sleeve compatible in diameter with the remaining pile is selected, and the new pile butt post is shaped to fit into the pipe or sleeve. If pipe is used, one-half of its length is fitted over the pile butt and fastened with 8-inch long by 3/8-inch diameter boat spikes. The pile butt and sleeve is placed over the cut off pile and maneuvered under the pile cap.

All ends, cuts and bolt holes are to be treated with creosote or other appropriate wood preservative specified in Chapter 3.

The new pile butt post is then shimmed tight against the pile cap and secured with a 7/8-inch diameter drift pin or 1-inch diameter galvanized bolts, depending upon the method selected for attaching to the pile cap.

If two or more adjacent piles are repaired in this way, it may be necessary to provide resistance to lateral loads imposed on the structure. This can be accomplished by installing X-bracing between piles, as illustrated in figure 6-5.

Application: This method works well where not many piles need repair. It is less expensive than driving new piles.

Future Inspection Requirement: Weak joints, with no movement capacity, may experience damage. All splices, holes and braces below MHW may be subject to accelerated marine borer attack.

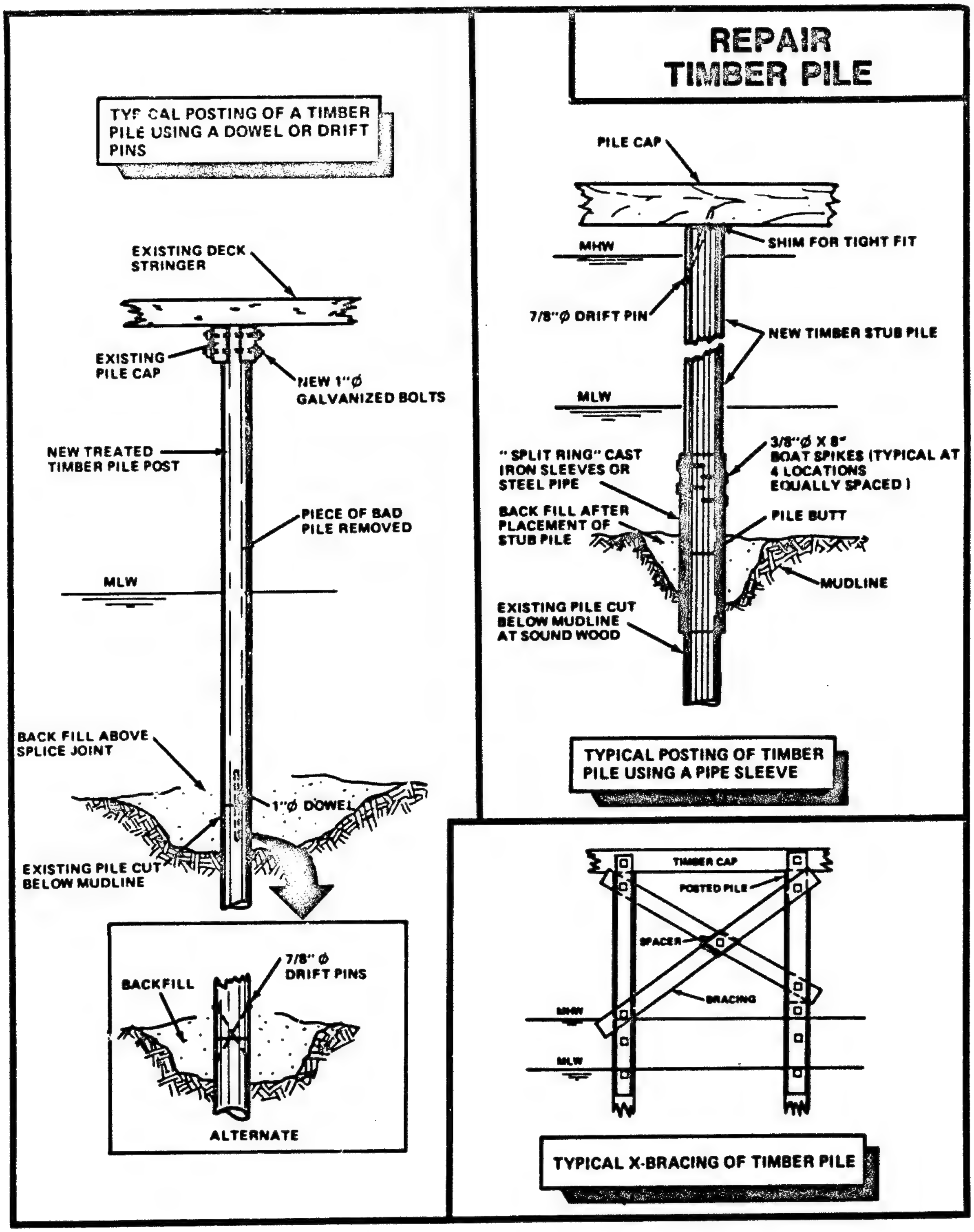


Figure 6-5. Posting Timber Pile with a New Pile Butt Post.

TR-6: REPAIRING TIMBER PILES WITH CONCRETE ENCASEMENT

Problem: Approximately 10 to 50 percent of the cross-sectional area has been lost as a result of marine borer attack.

Description of Repairs: Clean the timber pile thoroughly from below the mudline to above mean high water. Two types of forms are available:

- Flexible forms
- Split fiberboard forms

After the piles have been thoroughly cleaned, a 6- by 6-inch reinforcing mesh is placed around the pile, using spacers to maintain clearance between the pile, reinforcing, and fabric form. The fabric form should be placed around the pile.

For Flexible form, the zipper should be closed, and the form secured to the pile at the top and bottom with mechanical fasteners (figure 6-6).

For Fiberboard form, the straps are installed and secured every 12 inches. A minimum of 1-1/2-inch spacing is to be maintained between the pile and reinforcing and between the reinforcing and form (figure 6-6).

The space between the pile and the form is then filled to overflowing with concrete grout using a tube or hose extending down to the lowest point of the form.

The form is left in place and the base is backfilled to above the concrete.

Application: This method can be used as a repair or as protection to prevent marine borer attack and abrasion. May be more expensive than replacing one or more timber piles. Economics will dictate decision.

Future Inspection Requirement: Increased inspections may be required to detect signs of potential ripping of fabric forms, potential unzipping or unlocking of form seams, or abrasion and failure of concrete encasement.

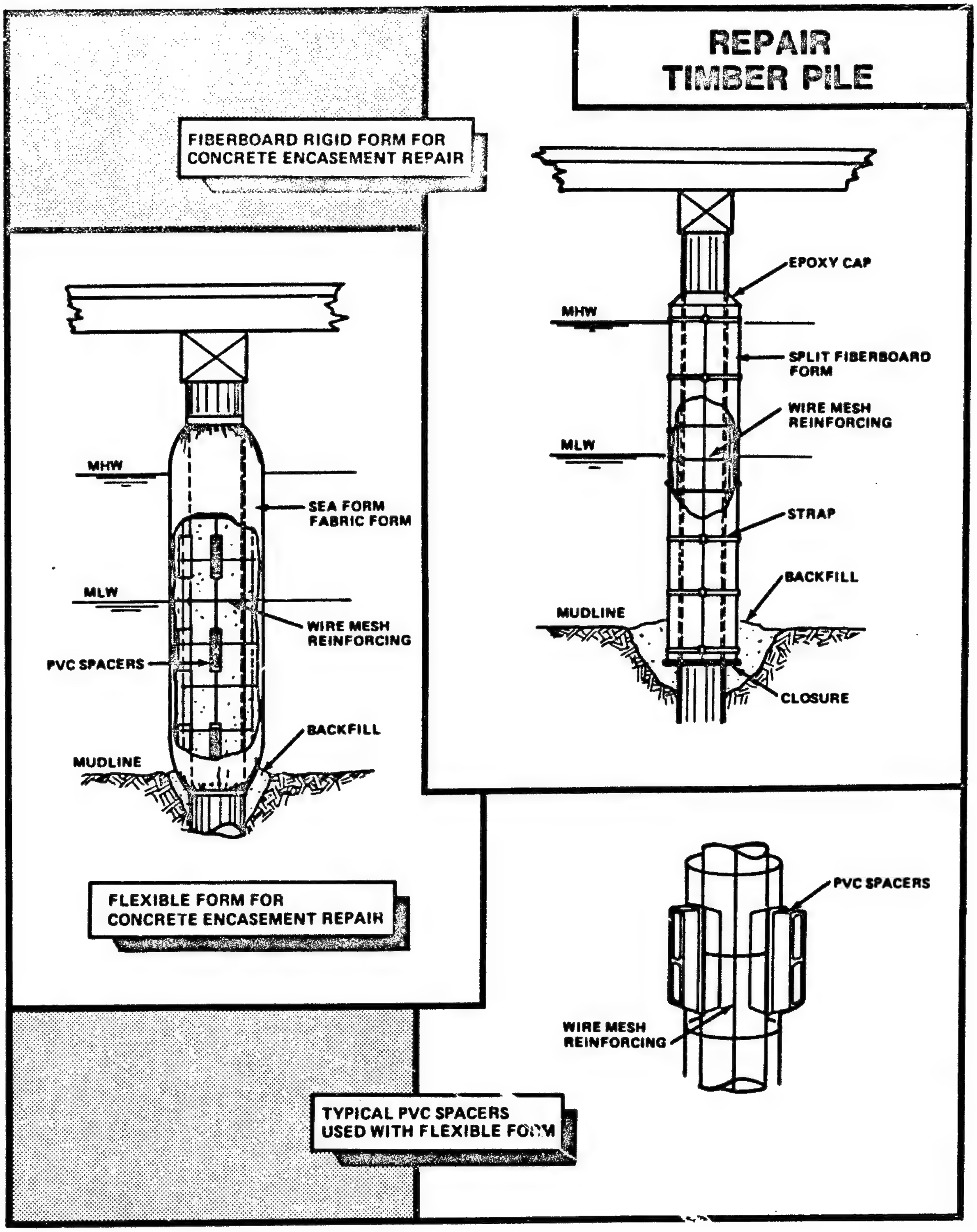


Figure 6-6. Concrete Encasement Repairs to Timber Pile.

TR-7: REPLACING DAMAGED PILE WITH NEW TIMBER PILE UNDER TIMBER PIER DECK

Problem: Physical damage or severe pile deterioration has been experienced below mudline, and/or number of piles with severe deterioration (above mudline) is too extensive to maintain structural integrity with partial pile replacement.

Description of Repair: Cut an opening in the timber pier deck adjacent to the damaged pile. Drive the new pile and cut to fit under the pile cap. Spring the pile into place (figure 6-7). Shim between the pile and pile cap, then fasten the pile to the pile cap with a 7/8-inch diameter drift pin.

Application: Limited mainly by cost. If fixed structures are on deck, this method may be uneconomical. If damage to the original pile(s) is due to marine borers, old pile(s) should be removed so that it does not provide bait to attract and nourish more borers. This application can also be used to replace damaged concrete or steel piles.

Future Inspection Requirement: Basically the same as for a new pretreated pile.

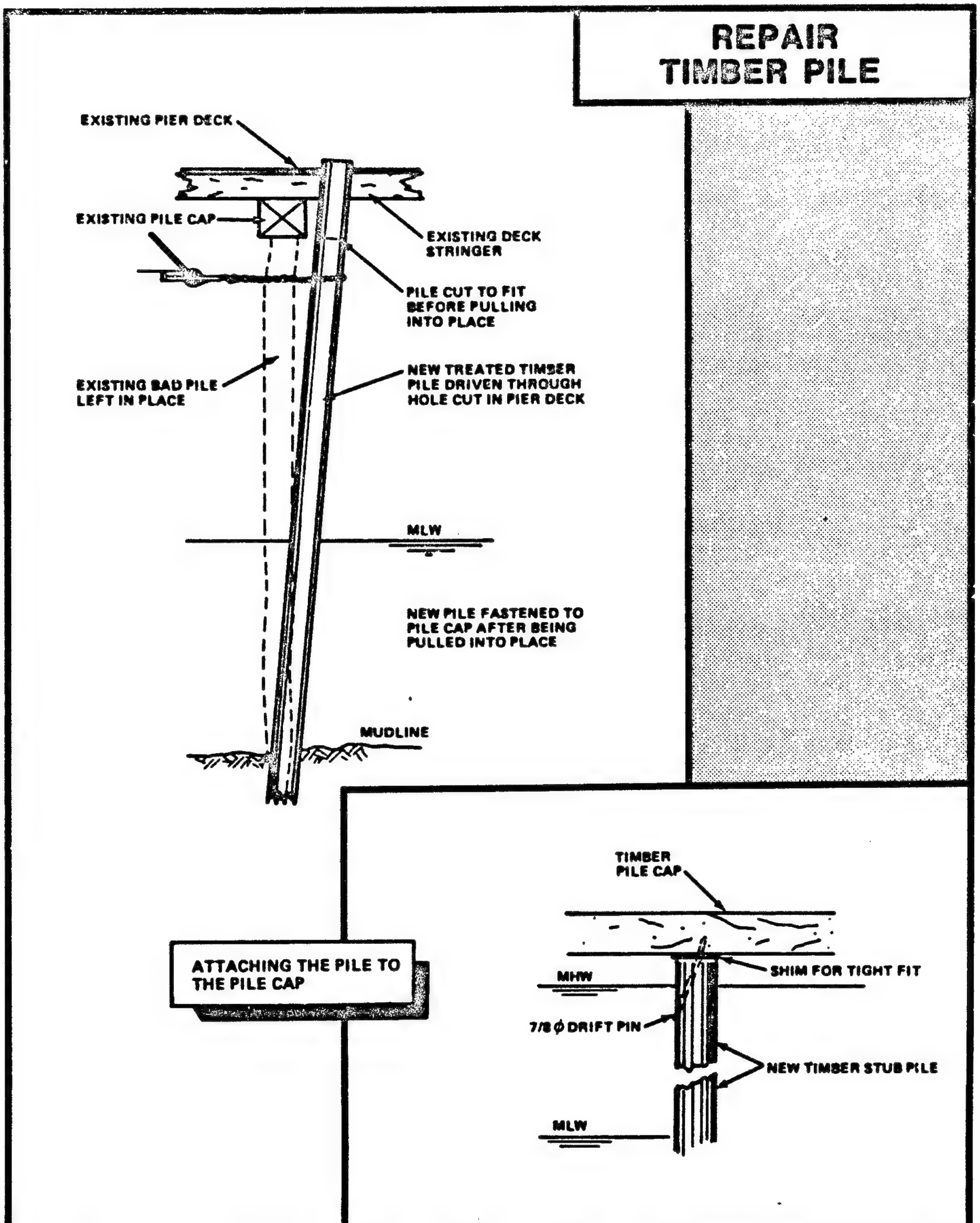


Figure 6-7. Replacing a Damaged Pile with a New Timber Pile.

TR-8: REPLACING DAMAGED PILE WITH NEW CONCRETE PILE UNDER CONCRETE DECK

Problem: Sufficient pile deterioration or damage has been experienced to significantly reduce the structural integrity of the section of the pier. Concrete pile cap and decking precludes replacing with timber pile.

Description of Repair: Cut a hole in the concrete deck between timber pile bents. Drive new concrete pile. Cut the pile below the top of the concrete deck. Form the capital under the deck, on top of the new pile. Cast the capital and the new section of concrete deck (figure 6-8) including splicing in new reinforcing bars. Epoxy coat bars where possible.

Application: Limited mainly by cost. If fixed structures are on deck, or if deterioration is wide spread, this approach may be impractical.

Future Inspection Requirement: Same as with new concrete piles and concrete deck areas.

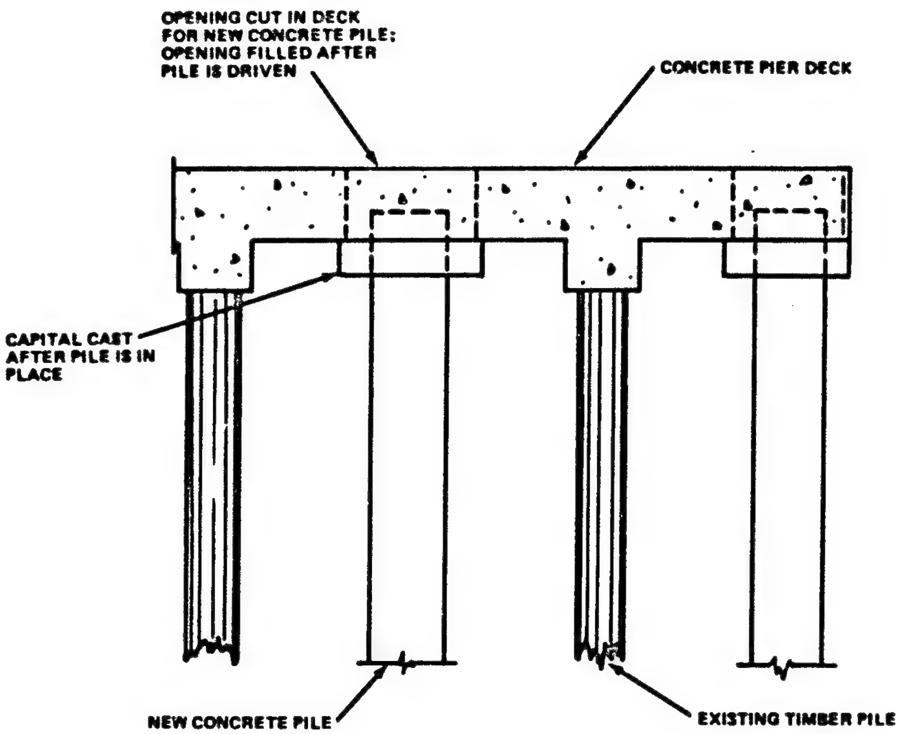


Figure 6-8. Replacing a Damaged Timber Pile with a New Concrete Pile under a Concrete Deck.

TR-9: PATCHING SMALL HOLES IN TIMBER SHEET PILING

Problem: Localized surface areas have deteriorated as a result of marine borer infestation or rot.

Description of Repairs: Clean deteriorated areas down to sound wood.

Underwater Cement Grout: Drive galvanized nails into the wood within the deteriorated areas to provide a mechanical connection for the patch. Fill the holes with a commercially available, underwater cement grout in the following manner: the grout is formed into grapefruit-sized balls on the surface, lowered to the diver in a bucket, and pressed by the diver into the hole (figure 6-9).

Ship's Felt and Plank Patch: Cover the area with creosoted ships's felt and fasten in place with galvanized roofing nails. Cover the felt with 1-inch thick treated boards and fasten with galvanized nails (figure 6-9). The boards may be either creosoted or treated with CCA or ACA waterborne salts. In tropical areas, dual creosote-waterborne salt treatment may be more advantageous.

Application: This type repair may be more applicable to northern climates where deterioration is slower. Use of this procedure may be more economical than replacing members or providing large patches. Need to ensure to the maximum extent practicable that marine borer attack has been arrested.

Future Inspection Requirement: More frequent inspections (minimum annual) are required to ensure that patches do not fail and that sheet piling does not buckle due to loss of strength.

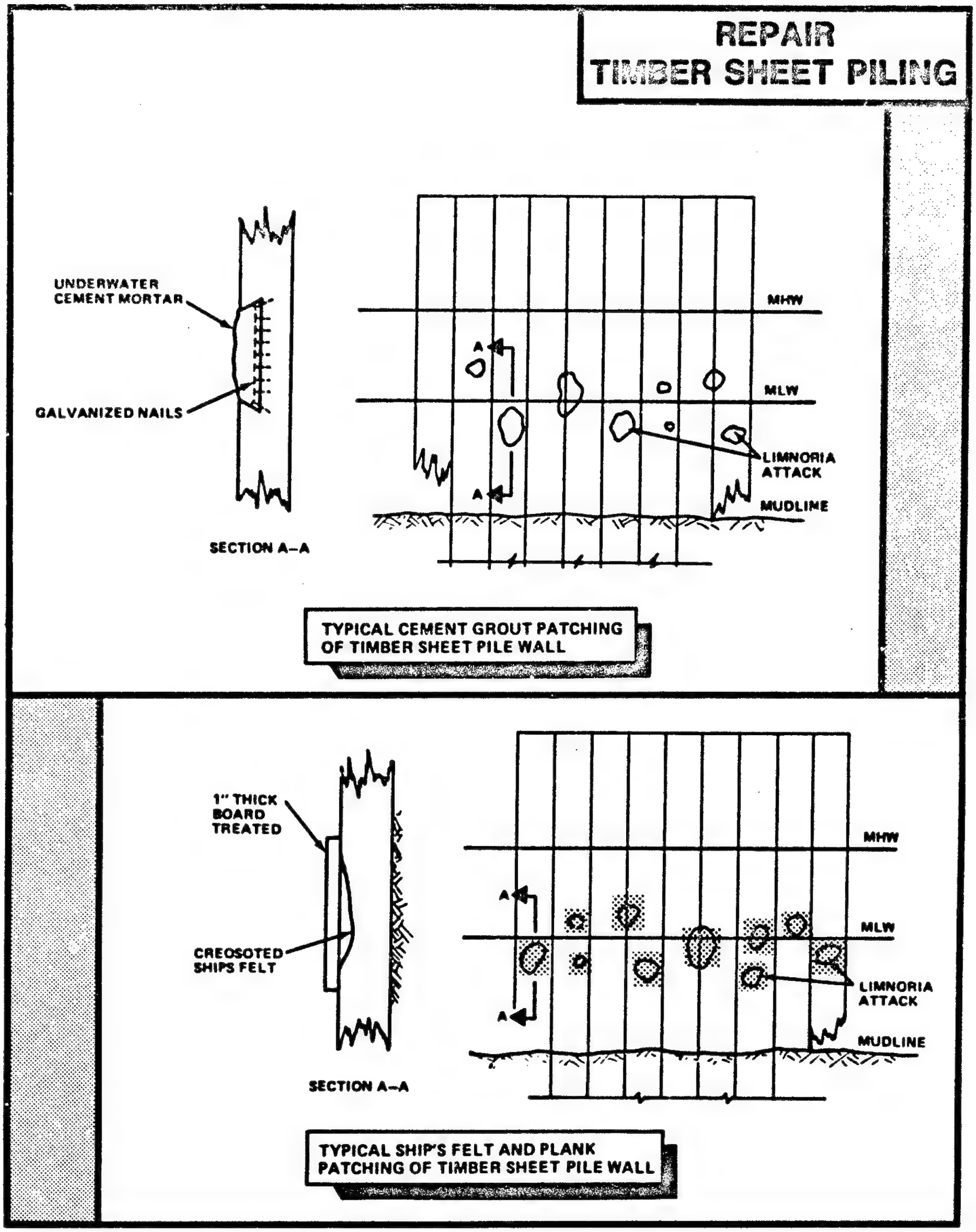


Figure 6-9. Patching Small Holes in Timber Sheet Piling Walls.

TR-10: PATCHING LARGE HOLES IN TIMBER SHEET PILING

Problem: Localized areas have deteriorated as a result of marine borer infestation or rot resulting in penetration of the sheet piling.

Description of Repair: Clean areas attacked or deteriorated, down to sound wood. Patch the holes accessible from the outside using timber or metal plates. Attach with appropriate fasteners.

Test for location of unknown leaks by driving pipe casings behind wall and pumping water or air through the casings.

Pump cement/water grout into succeeding pipe casings until indication at each pipe that ground behind wall and holes in wall are sealed (figure 6-10).

If deterioration of timber walls is extensive, sheet piling (usually steel) is driven to form a new bulkhead a minimum of 1 foot behind the existing wall, in order to avoid the driving frames or wales attached to it. Drive new sheet piles a minimum of 3 feet below the toe of the deteriorated wood sheeting. The fill at the inside edge is usually removed before driving the new sheet piling. When this is done, a concrete cap should be placed over the new sheeting to form a seal with the existing construction.

Application: This type of repair, involving patching, requires experience in testing and grouting. Repairs of this type will most likely be accomplished by contract and may be costly due to unknowns associated with estimating grout requirements. Replacement with a new bulkhead is more conventional.

Future Inspection Requirement: More frequent inspections (minimum annual) are required to ensure that patches do not fail and that sheet piling does not buckle due to loss of strength.

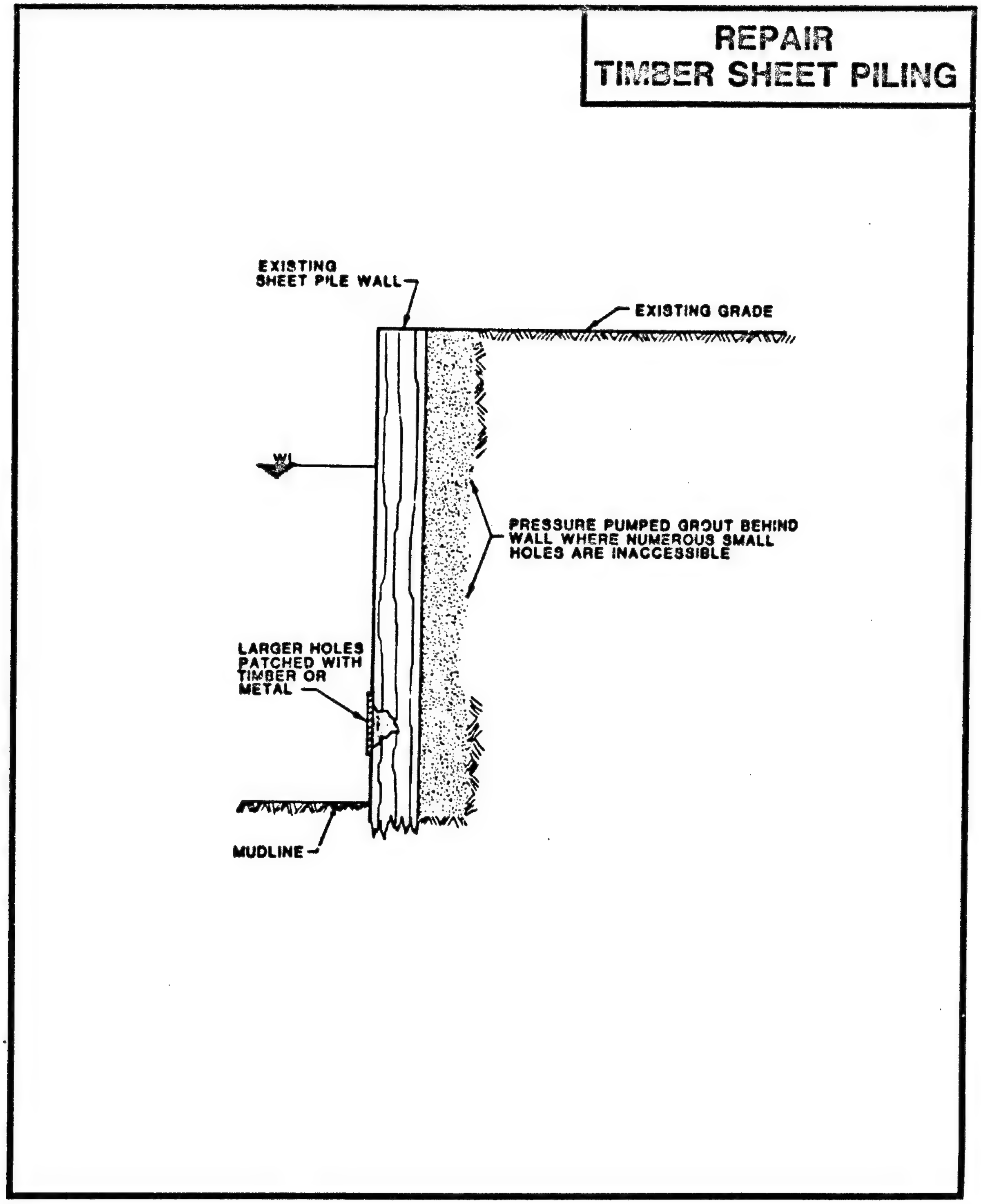


Figure 6-10. Patching Large Holes in Timber Sheet Piling Wall.

TR-11: REINFORCING TIE-BACK SYSTEM FOR TIMBER SHEET PILING WALL

Problem: Light to moderate movement of the top of the timber sheet piling wall has occurred due to tie-back failure or excessive loading behind the wall. The area behind the wall is accessible to perform repairs.

Description of Repairs: Install a new wale slightiy above the existing wale. Locate the new deadman anchors based upon engineering calculations. Trench for the tie rods between the wall and the deadman anchors. Place the tie rods through the wale and sheet piles and secure in place to the deadman anchors (figure 6-11). Install zinc or magnesium packaged anodes to prevent further corrosion of the rods.

Replacement of an existing tie-back system may involve the replacement of any or all of the existing components, depending on the amount of deterioration that has taken place.

Sheet pile wall movement can also sometimes be arrested by changing the soil loading acting on the wall. For example, stone riprap dumped against the exterior toe of the wall will add resistance to the movement of the toe. Alternatively, or in addition, backfill can be removed from behind the wall and replaced with lightweight granular fill. This type of fill has the advantage of being free draining, which reduces the hydrostatic pressure behind the wall and allows the water level on both sides to balance.

Application: Reinforcing or replacing the tie-back system may be restricted to correction of slight to moderate wall deflection. Excessive deflection may require wall replacement or major restoration. With timber construction, it is unlikely that excavation and pulling the wall back into position can be accomplished without high risk of failure of timber members.

Future Inspection Requirement: Careful attention must be given to inspecting the wall for further signs of continued deflection or timber member failure.

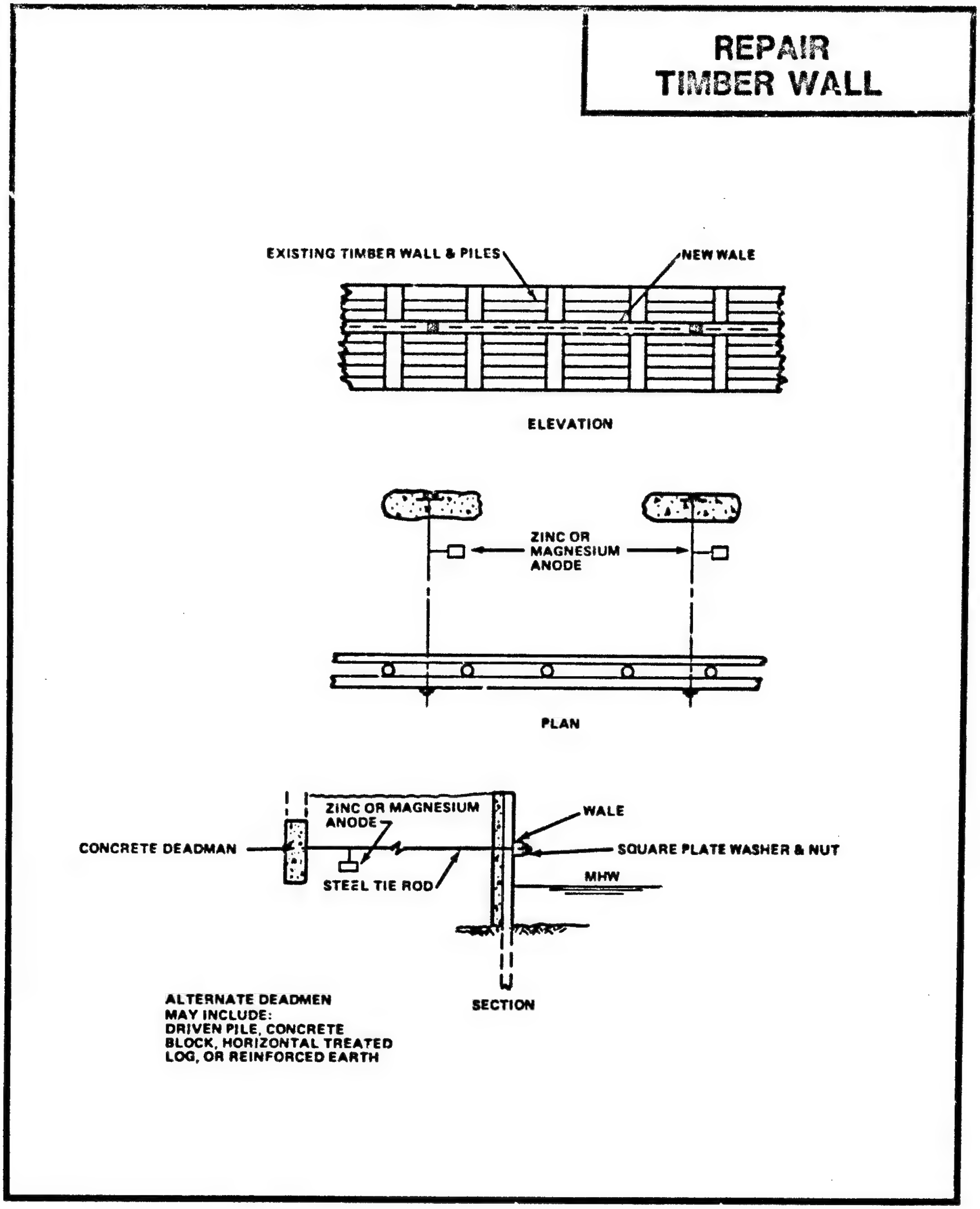


Figure 6-11. Installing or Replacing Tie-Back System for Timber Sheet Piling Wall.

TR-12: INSTALLING A TIE-BACK SYSTEM ON THE TOP OF A SHEET TIMBER PILING WALL

Problem: Movement of the top of the timber sheet piling wall has occurred, lightly to moderately, due to tie-back failure or excessive loading behind the wall. The area behind the wall is inaccessible for repairs.

Description of Repair: Cast a new concrete slab with extra reinforcing, from the face of the wall back behind the wall to the end of the existing slab. Tie the front edge of the new slab to wall through use of a steel angle (figure 6-12).

Application: Limited; additional restraint is limited to top of sheet piling. If excessive loading or loss of regular tie-back anchors are experienced, further failure including shearing of sheet piling tops may occur.

Future Inspection Requirement: Careful attention must be given to inspecting the wall for further signs of continued deflection or timber member failure.

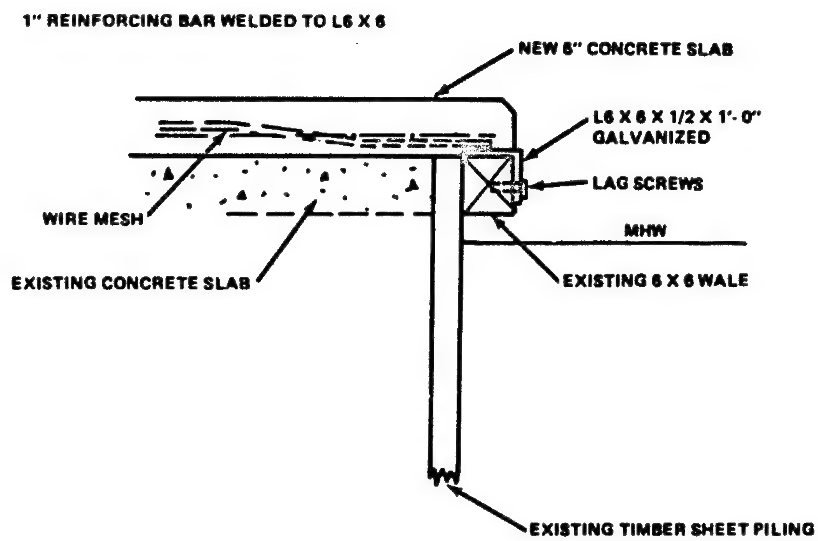


Figure 6-12. Installing a Tie-Back System at Top of a Timber Sheet Piling Wall.

TR-13: INSTALLING A CONCRETE CAP/FACE ON A TIMBER SHEET PILING WALL

Problem: Large-scale deterioration of the timber sheet pile structure has occurred precluding the use of patches for repairs.

Description of Repairs: Excavate the soil from behind the wall to a level required for the new concrete cap or attachment of form ties for a concrete face. Remove all marine growth and deteriorated wood, and clean surfaces.

> **For Concrete Cap:** Build forms, place reinforcing and pour concrete at Mean Low Water (MLW). After curing, remove forms and backfill behind wall (figure 6-13).
>
> **For Concrete Face:** Place and fasten blocking and low wale against existing sheet piling. Drive the timber sheet pile wall about one foot in front of existing sheet piling using wale as guide. Attach outside wales to timber sheeting and place concrete by pumping or tremie. Leave timber sheet piling in place or remove as desired (figure 6-13).

Application: Used to restore structural strength at the top of the wall (cap) or prevent further loss of soil through holes in the sheet piling (face). Does not restore bending moment capacity in wall. Provides protection against further deterioration.

Future Inspection Requirement: Careful inspection should be made annually involving the sheet piling areas immediately under the pile cap, in order to ensure that fungi, insect or marine borer damage is not significantly weakening the support for the concrete cap.

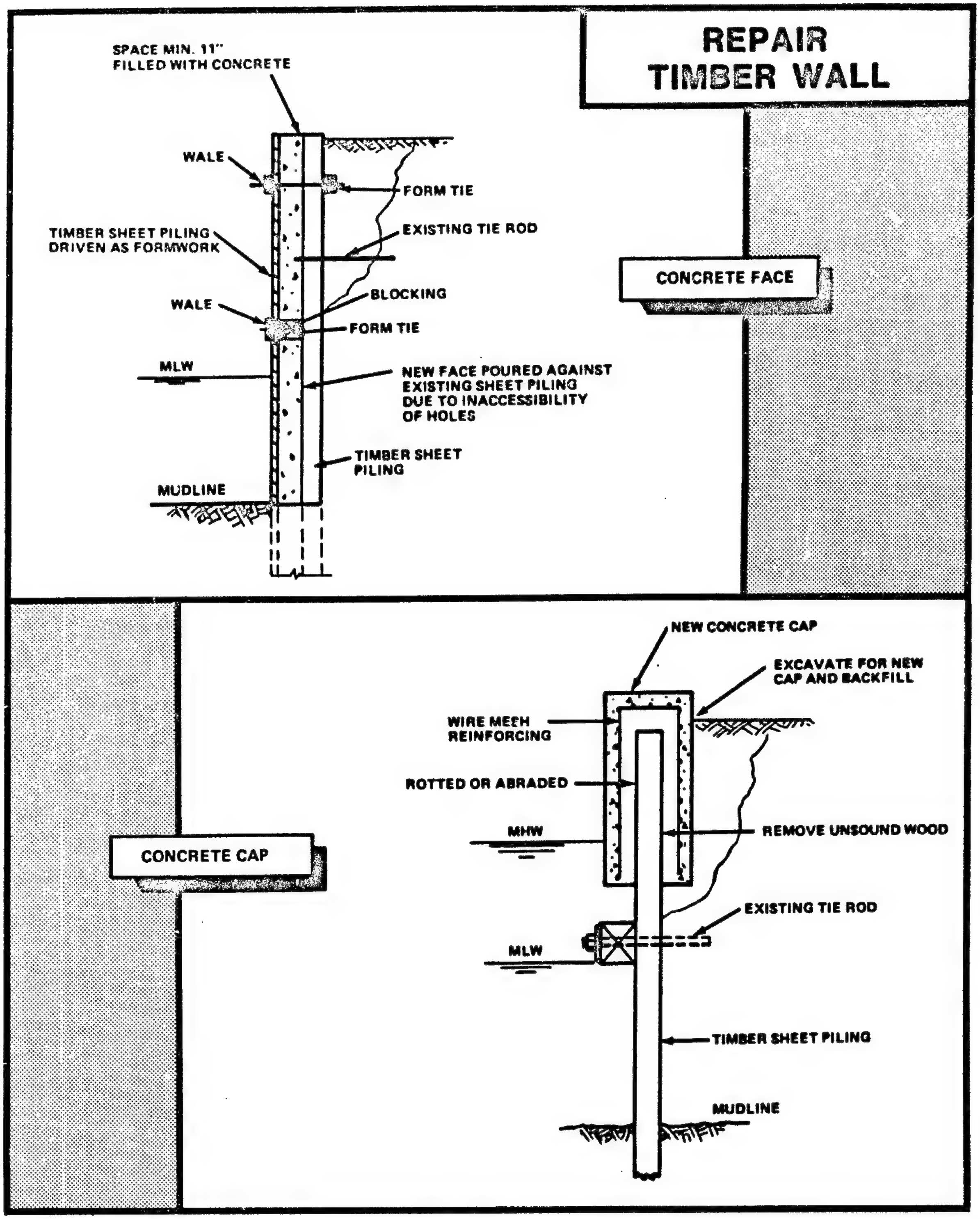


Figure 6-13. Installing a Concrete Cap and/or Face on a Timber Sheet Piling Wall.

TR-14: REPAIR OF DOLPHINS

Dolphins and Support Systems:

The repair of timber dolphins includes the replacement of fastenings, blocking, and any rope wrapping that has become corroded or worn. Damaged or deteriorated timbers of connecting catwalks should be replaced with treated timbers; steel members should be cleaned and painted, or replaced.

If it is necessary to replace any piles, the fastenings should be removed only as far as is necessary to release the piles that are damaged. Care should be taken to drive the new piles at an angle so that they will not have to be pulled to far to fit them in place. The size of piles to be replaced should be carefully noted, particularly at the head or intermediate point where they are fitted together with the other piles. Much trouble in cutting and fitting the replacement piles can be avoided by selecting piles with the proper size head. All replacement piles should be driven before a ny are brought together. After all piles are driven, the center cluster should be brought together first, fitted, chocked, bolted, and pinned; when all rows have been properly fitted, etc., they are then wrapped with wire rope. All cuts in piles for fittings, bolts, and wrappings should be thoroughly field-treated with creosote. These cuts should be avoided as far as possible because field treatment with creosote gives only marginal protection against marine borer attack.

Protection may be provided for dolphin piling by using PVC wraps. See repair technique TR-3.

CHAPTER 7. REPAIR OF CONCRETE STRUCTURES

7.1 CONCRETE FOR REPAIRS. Quality, lasting concrete for repair of waterfront facilities depends upon the quality of the concrete mix, and careful attention to preparation and construction techniques. Both factors are important in making and placing conventional portland cement concrete and the special types of repair concretes.

Some of the information in this chapter was extracted from the following references:

- Design Manual NAVFAC DM-25.06, General Criteria for Waterfront Construction (reference 7).
- Survey of Techniques for Underwater Maintenance/Repair of Waterfront Structures, Revision No.1, Childs Engineering Corporation (reference 19).
- NCEL TM-43-85-01 O&M, UCT Conventional Inspection and Repair Techniques Manual (reference 36).
- CEL CR 81.009, Survey of Techniques for Underwater Maintenance/ Repair of Waterfront Structures, Childs Engineering Corporation (reference 39).

7.1.1 Portland Cement Concrete

7.1.1.1 Important Properties.

a. **Durability.** Concrete of low permeability is very important for waterfront facilities. The objective is to keep salt and water out of the concrete to protect the reinforcing steel from corroding, which result in the concrete spalling. The most important factors are a low water-to-cement ratio (0.40) in the mix, and proper curing of the concrete when placed.

b. **Strength.** 4500 psi concrete is recommended for most repairs. Design of the mix and proper curing will determine the final strength.

c. **Workability.** Particularly for difficult and hard to access repair jobs, the concrete must be easily handled and placed. A dense concrete is important. This workability must be obtained **without increasing the water content** beyond the mix design. A workable concrete can be obtained by use of a water-reducing admixture and by rapid handling and placing after mixing. Use admixtures conforming to ASTM C-494 types A, D, E, F and G.

7.1.1.2 Preparation and Construction. To obtain quality concrete repairs, the following basics are mandatory for all jobs:

- **Properly prepare the surface** of the old concrete to be adjoined.
- Ensure **a good bond** between the old and new concrete.
- **Do not add** more **water** than specified for the concrete mix.
- **Do not patch** across **active cracks** or **joints.**
- **Cure** the concrete **properly.**

a. **Surface Preparation.** All deteriorated concrete must be removed down to sound concrete. For some old concretes, exposed surfaces will soften after a few days of exposure; therefore, the surfaces should be checked closely before final patching operations. Clean the old surface thoroughly just before placing new concrete.

Normally, concrete removal is performed with hand tools or light duty hand-held power tools, particularly around the edges, to prevent damage to the remaining concrete. Edges should be square, preferably cut by sawing to about a 1-inch depth. Feathered edges must be absolutely avoided. Inside corners of a cavity should be rounded to a 1-inch radius. Reinforcing bars should be exposed around their entire circumference by a clearance of 1 inch.

Sandblasting surfaces removes loose concrete fragments and scaling rust from steel. Once the steel is clean, it can be protected by coating with a slurry of portland cement grout or latex modified portland cement grout. This procedure improves the life of the repair.

b. **Bonding.** Before patching, the existing base concrete should be kept damp (except for epoxy concrete repair) for several hours, preferably overnight. Remove free water or shiny wet areas by vacuuming or with oil-free compressed air. A bonding agent should then be scrubbed into the surface. The bonding agent can be portland cement mortar, latex modified portland cement mortar, or epoxy resin. The mortars should be 1 part cement and 1 part sand passing the No. 30 sieve, and have a consistency of thick cream. If an epoxy bonding agent is used, follow the manufacturer's recommendations precisely. In all cases, it is important to place the repair concrete before the bonding agent dries.

c. **Curing.** Concrete used in repairs must be protected and cured more carefully than usual. The old concrete could absorb moisture too rapidly from the new concrete, or the temperature of the old concrete could be too low to permit early development of strength of a concrete patch.

Curing is important to allow strength development and prevent drying shrinkage. For portland cement mixes, water curing by ponding with water, fog misting, or covering with wet burlap are the best methods. Other acceptable

GUIDELINES FOR CONCRETE USED IN WATERFRONT REPAIRS

- Use 4500 psi concrete.
- Use **Only** Type II or Type V cement.
- Use a minimum of 600 lbs (6.4 bags) to a maximum of 750 lb (8 bags) of cement per cubic yard in the concrete mix.
- Use a maximum water-cement ratio of 0.40 by weight (4.5 gallons per bag of cement).
- For most small volume repairs, use aggregate no larger than 3/4 inch.
- Make sure concrete cover over reinforcing steel is at least 3 inches.
- Use epoxy-coated reinforcing steel, or epoxy coat exposed steel, in situations where steel is particularly susceptible to corrosion.
- Give particular consideration to use of admixtures:
  - **DO NOT** use an admixture containing chloride.
  - For concrete subject to freeze-thaw cycles, use air-entraining agent to obtain 5 to 7 percent air content.
  - Use a water-reducing admixture (ASTM C 494) when concrete is placed in area congested with reinforcing or in pours difficult to consolidate. This will decrease chance of voids and temptation to add water to the concrete.

SPECIFIC GUIDELINES FOR UNDERWATER CONCRETE

- Water-cement ratio must not exceed 0.45 (5 gallons per bag of cement).
- Use a minimum of 750 lb (8 bags) to a maximum of 940 lb (10 bags) of cement per cubic yard.
- Use an air-entraining admixture to obtain 3 to 6 percent entrained air for improved workability.
- Use a water-reducing plasticizing admixture.

methods include covering with plastic sheeting material or coating with curing compound. The repair concrete should be kept wet or moist for a minimum of 7 days. When water evaporates from the concrete, drying shrinkage occurs. Shrinkage of a patch can cause the patch to crack or partially debond.

Curing for epoxy concrete is to provide the correct temperature for the epoxy resin to develop full strength. Epoxy resins that use 100 percent solids and no solvents do not shrink. Epoxy resins do, however, have a much greater coefficient of expansion than concrete. This can lead to failure in large patches and in environments that experience large temperature differentials between day and night. Epoxy can be mixed with sand (1 part epoxy: 7 parts sand) to minimize the difference in the thermal expansion characteristics.

7.1.2 Special Types of Repair Concrete

7.1.2.1 Fiber-reinforced Concrete. Concrete and mortar containing fibers of steel, glass or polypropylene are sometimes used in repair work. Fiber reinforcement provides improved tensile strength, toughness and ductility to concrete. The fibers reinforce crack repair material by distributing tensile strains.

Fiber-reinforced shotcrete has good potential for marine repair work. In some applications, the fibers can replace steel mesh. Although steel fibers corrode near the surface, at interior sections they are protected from corrosion by the high alkali of the cement paste. Steel fibers are typically from 0.01 to 0.20 inches in diameter and 0.50 to 1.50 inches long. The quantity of steel fibers used varies from 50 to 150 lb/yd^3.

Glass fibers in concrete can lose strength over periods of time in a wet environment. Polypropylene fibers are a new development. Neither are recommended for use in waterfront repair concrete because criteria have not been developed for their effective use.

7.1.2.2 Latex Modified Portland Cement Concrete. Latex modified portland cement concrete should not be confused with epoxy or polymer concrete discussed in paragraph 7.1.2.3. Latex modifiers improve the bond and tensile strength and reduce the permeability of portand cement concrete. Latex formulations of acrylics, styrenebutadiene, and polyvinyl acetates are available. The first two latexes are suitable for wet environments. Polyvinyl acetates should not be used in concrete for repairs exposed to water. Latex modified concrete is recommended for overhead and vertical repairs when placed in lifts less than 1.5 inches.

Latex modified concrete, compared to epoxy concrete, is vapor permeable and lower in cost. Even though permeable to vapor, it is not very permeable to liquids. Repairs requiring thin sections, which will be exposed to the sun, should be breathable so that vapor pressure does not build up behind the patches or overlays. Vapor pressure can debond and cause a patch to spall off.

Recommended mix proportions for thin and medium thickness repairs are:

	Finished Thickness 1/2" - 1 1/4"	1 1/4" Up
Latex-to-cement ratio	0.10 to 0.20	0.10 to 0.20
Water-cement ratio	0.30 to 0.40	0.30 to 0.40
Fine aggregate to 1 part cement	3.0 to 3.5 parts	2.5 to 3.1 parts
Coarse aggregate to 1 part cement	2.5 to 3.1 parts	1.4 to 2.0 parts
	2.5 to 3.1 parts	1.4 to 2.0 parts

Prepackaged latex modified mortars, or just the liquid latex modifiers, are commercially available. The mortar mixes can be converted to concrete by adding coarse aggregate. Latex modified concretes are very sensitive to improper placement techniques, and noted failures have occurred. Manufacturers' recommendations should be followed very carefully.

7.1.2.3 Epoxy Concrete. Epoxy concrete does not contain portland cement. It is a mixture of an epoxy resin and aggregate. Epoxy concrete is the most popular type of polymer concrete because of the many physical properties that can be obtained, its good adhesion to existing concrete, and availability. Other commercially available polymers are acrylics, polyesters, polyurethanes, and polyvinyl acetate.

Epoxy resin, when mixed with a curing agent, forms a thermosetting plastic that rapidly develops adhesive strength. Epoxy mixes are used for several purposes: to repair cracks by injecting the resin, to bond repair material to the base concrete by brushing on the resin, and to make epoxy mortar or concrete by mixing the resin with fine and coarse aggregate.

Because the cost is relatively high and the material is relatively inflexible in thick layers, epoxy concrete is used mainly for thin section repairs. Proprietary, prepackaged systems should be used. Generally, the aggregate is a silica sand with little or no material passing the No. 100 sieve (dust). The aggregate must be clean and absolutely dry. Not all epoxy resins will bond to damp or wet concrete, so check the manufacturer's specifications.

Epoxy systems used in repairs provide excellent protection in keeping seawater and oxygen out of the concrete.

Epoxy mortars consist of 1 part epoxy resin to 4 to 7 parts sand by weight. The resin is usually of two components that are batched by volume and thoroughly mixed before combined with aggregate. Epoxy concrete contains 1 part epoxy resin to 6 to 10 parts aggregate by weight. Equal parts of the fine and coarse aggregate are used. Epoxy concrete should be placed in layers no more than 2 inches thick, so that excessive heat build up does not occur.

7.2 PLANNING THE REPAIRS. The first steps in planning a repair will be to: (1) conduct an inspection to determine the scope of damage or deterioration, (2) determine operational or functional constraints on the facility because of the needed repair, and (3) establish a priority for the repair. Based on these factors, planning will then proceed to determine in-house or contract accomplishment, the repair technique to be used, method of placing the

concrete, special skills required, and unique equipment requirements. If underwater repairs are involved, special attention must be given to planning for the unique requirements, particularly involving safety.

7.2.1 Special Skill Requirements. Most concrete repair techniques and methods of placement require the normal skills associated with concrete construction; building forms, setting reinforcing steel, mixing concrete, vibration, finishing, and curing. Special skills and experience are required for placement of shotcrete and for handling and placing concrete for underwater repairs. Shotcrete, in particular, requires a skilled nozzle operator to ensure quality results. The use of epoxy components, epoxy injection, and sealing of cracks and joints require experienced personnel.

Underwater repairs, depending upon the complexity of the job, can require special skills beyond placing the concrete such as knowledge and experience in removal of marine growth, underwater jetting and blasting, use of underwater tools for cutting and drilling, and the use of certain materials for coating and caulking underwater.

7.2.2 Special Equipment Requirements. Unique equipment requirements will exist on many jobs and will often dictate the personnel skill requirements. Application of shotcrete requires a complete set of special equipment, as does pumped concrete. See the outlines in placement methods CPM-4 and CPM-6. Also, underwater work can require the same equipment listed in paragraph 6.3.2.

Above water repairs will require conventional equipment for surface abrasive blasting and air-jet cleaning, form construction, and mixing, placing and finishing concrete.

7.3 METHODS OF PLACING CONCRETE AND MORTARS. This section outlines the seven most common methods for the placement of concrete and mortars in waterfront repair.

CONCRETE PLACEMENT METHODS

- **CPM-1: Hand Placement**
- **CPM-2: Dry Pack**
- **CPM-3: Cast-in-place**
- **CPM-4: Shotcrete**
- **CPM-5: Tremie**
- **CPM-6: Pumped**
- **CPM-7: Prepacked**

CPM-1: HAND PLACEMENT

Description: Troweling a mortar into shallow, relatively small areas requiring patching.

Uses: Patching surface areas small enough for hand work and shallow cavities not suitable for dry pack.

Restrictions/Cautions: Take careful measures to prevent drying shrinkage by proper curing.

Preparation:

a. Remove all loose and unsound old concrete.
b. If reinforcing steel is exposed, ensure 1 inch clearance all around and wire brush steel bar.
c. Thoroughly clean repair area immediately before applying bonding coat.

Bonding: Brush coat repair area with sand-cement grout: 1 part Type II cement; 1 part sand; enough water for a consistency of thick cream.

Mortar Mix: The proportions of the mix will be dependent upon the overall size and depth of the repair, accessibility, and whether the repair is large enough to require coarse aggregate. A typical cement-to-sand ratio is 1:2.5 to 1:3. The water-cement ratio should be no greater than 0.40.

Placement:

a. If repair is in direct sun or wind, erect shade/wind break and leave in place during curing period.
b. Wet surface of repair area. Do not leave any free water.
c. Coat surface of the repair area with bonding grout with a brush.
d. Immediately trowel on mortar mixture ensuring complete filling of voids and dense placement.

Curing: Use a curing compound or wet burlap.

CPM-2: DRY PACK

Description: Packing a stiff mortar into a confined hole or cavity.

Uses: Filling narrow slots cut during repair of dormant cracks, and filling cavities/holes small in cross-sectional area but relatively deep.

Restrictions/Cautions:

a. Use for holes no larger than 36 square inches in cross-sectional area.
b. The depth of the cavity should be equal to or greater than the smallest surface dimension.
c. DO NOT use for:
   (1) shallow depressions where lateral restraint is not obtained.
   (2) filling behind exposed reinforcing steel.
   (3) holes that extend through the structure.
d. Maintain water content of mortar carefully.

Preparation:

a. Thoroughly clean cavity.
b. Remove all loose or cracked aggregate.
c. Allow to dry at least 2 days before packing.

Bonding: Coat inside of cavity with a stiff bonding grout: 1 part Type II portland cement; 1 part clean, dry fine sand; enough water for a consistency of thick cream.

Dry Pack Mix: 1 part cement; 2.5 parts sand passing No. 16 sieve; only enough water so mortar sticks together when squeezed with slight pressure.

Placement:

a. Place and compact in layers 3/8 inches thick.
b. Scratch surface of each layer for good bond of next layer.
c. Fully compact each layer over entire surface with hardwood stick and hammer.
d. If a layer becomes rubbery, delay about 30 minutes for mortar to stiffen and then compact.
e. Finish surface with flat side of stick. Steel tools and water are not recommended.
f. Patch is usually darker than surrounding concrete. For appearance, use white cement in mix for outside layers.

Curing: No special requirements; however, a mist spray of water will enhance the durability of the repair.

CPM-3: CAST-IN-PLACE CONCRETE

Description: Placing conventional concrete mix with a concrete mixer truck, chute, bucket, wheel barrows, concrete carts, or shovels.

Uses: Used in all repairs where the quantity of concrete required is too large for hand placement, and where special placement methods CPM-4 through CPM-7 are not required. Control of the concrete mix and strength of the completed repair is much better than with any other methods. Should be used when:

- The hole/cavity extends through the concrete section.
- The cavity in unreinforced concrete is larger than 1 square foot in area and over 4 inches deep.
- The cavity in reinforced concrete is over 1/2 square foot in area and deeper than the reinforcing steel.

Major concerns are quality of the mix, good bonding to old surfaces, keeping a low water-cement ratio, and proper curing.

Restrictions/Cautions:

a. Temperature shall be over 40°F during placement.
b. Concrete can settle, even after proper consolidation, and create a gap between sections or a top elevation lower than required.
c. Ensure good consolidation of the concrete in restricted pours.

Preparation: See repair procedure CR-3. Give particular attention to:

a. Delay several days after demolition of old, deteriorated concrete to confirm the soundness of remaining concrete and excavated surfaces.
b. Check forms for tightness and stability.
c. Ensure that old surfaces are cleaned before repairs begin.
d. Ensure that reinforcing steel is cleaned of rust and scale and exposed at least 1 inch all around.

Bonding: Usually, a sand-cement grout will suffice. See repair CR-3.

Concrete Mix: Give particular attention to:

a. Use a concrete with as low a slump as practicable; 2 inches to 4 inches is desirable.
b. Consider moisture in aggregate when calculating quantity of water.
c. Use a water-reducing plasticizer admixture wherever placement and consolidation are restricted, or slumps greater than 4 inches are required.

Placement: The equipment used will depend on size of the pour, accessibility and working space, and availability of equipment. Concerns are speed of placement and consolidation. In confined, hard to access locations, consolidation should be aided by admixtures, and mechanical vibrators and tampers. Elimination of voids and honeycombing is very important.

Curing: Use the most effective moist-curing method for the repair circumstances. Do not cut corners or try to economize. This is critical.

CPM-4: SHOTCRETE (GUNITE)

Description: Sprayed concrete applied directly by an air jet gun. Equipment includes a mechanical feeder, mixer, and compressor. In dry-mix type, water is added at the nozzle.

Uses: Shotcrete is relatively economical where deterioration is shallow and area to be repaired is large and irregular in shape. It requires no formwork and thin patches can be made that have a high strength. It is an efficient method for vertical and overhead surfaces. It is also used for encasing timber and steel piling.

Restrictions/Cautions:

a. Must be sufficient repair work to justify cost of equipment.
b. Normally restricted to depth of 4 inches per lift.
c. Can have a high porosity if improperly applied.
d. Drying shrinkage rate and thermal expansion can be considerably different than concrete being repaired.
e. May have wide variation in application/composition. Quality depends almost entirely upon skill of the operator. Follow ACI SP-14 guidelines.

Preparation.

a. Thoroughly remove all defective and loose concrete.
b. Clean all rust off exposed reinforcing steel.
c. Roughen all smooth surfaces.
d. Wire brush or abrasive blast exposed concrete surfaces to be covered.

Bonding: A bonding agent is not required.

Shotcrete Mix:

a. Cement-to-aggregate maximum ratio 1 to 3.5. This will result in an in-place mix of about 1 to 2.5 after rebound.
b. Minimize the water-to-cement ratio.
c. May use a non-chloride type admixture for rapid setting.
d. Fiber reinforcing may help minimize shrinkage cracks.

Placement:

a. Install reinforcing wire fabric to ensure the laps project no more than 3/4 inch from surface being covered.
b. Usually, start work at bottom and move up; may follow the tide down.
c. Fix the profile.
d. Fill out the area to the original face.
e. Apply each coat at least 2 inches thick. Final coat at least 1/2-inch thick.
f. Ensure that rebound material is not trapped in corners or edges.
g. Ensure reinforcing bars are properly encased.

Curing: Shotcrete has a high drying shrinkage. Optimum moist-curing method should be used.

CPM-5: TREMIE CONCRETE

Description: The primary method of placing concrete underwater when gravity flow is adequate. The tremie, a steel tube or rigid hose, runs from a hopper for filling its upper end into the form and is moved horizontally as the concrete is placed.

Uses: All underwater pours at easily accessible locations that require a quantity of concrete sufficient to warrant the equipment set-up.

Restrictions/Cautions:

a. Do not use an aluminum alloy tremie to avoid reaction with the concrete mix.

b. Location, and space in the form, must be accessible for positioning and moving the tremie vertically and horizontally.

c. Slump of concrete mix must be carefully controlled within 6 to 8 inches. Too wet a mix may segregate and too dry a mix will not flow properly in the form.

d. If practicable, place concrete when water temperature is above 50°F.

Preparation: Preparation of the repair location is the same as for cast-in-place concrete. Also, ensure that the tremie pipe is heavy enough to be negatively buoyant, and that the joints in the tremie are well-gasketed and sealed. The diameter of the tremie should be at least 8 times the largest size aggregate used.

Bonding: Not usually required.

Concrete Mix:

a. A typical mix proportion for cement, sand, aggregate, is 1:1.7:2.4 by weight with a water-cement ratio of 0.45.

b. Use air-entraining and water-reducing plasticizer admixtures as required for the underwater repair. Admixtures conforming to ASTM C 494 are acceptable.

c. Use a mineral admixture of pozzolan in thick sections to control heat buildup. This will reduce amount of cement in the mix.

Placement:

a. Once the tremie pipe is filled, lift the bottom end from the bottom of the form carefully not more than 6 inches to initiate flow of concrete.

b. Placement should be as continuous as possible. The end of the tremie must remain embedded in the concrete by as much as 3 feet.

c. If the tremie is lifted out and the seal is lost, remove it, reseal, and restart.

d. Move the tremie horizontally while concrete is flowing.

Curing: Not applicable.

CPM-6: PUMPED CONCRETE

Description: Placing concrete through a pipe or hose by means of a concrete pump with attached hopper.

Uses: Often used for placement above water. May be used for underwater placement in locations with limited accessibility, where the tremie method is not efficient. The advantages for underwater repairs include:

- High quality concrete is required because the mixture must be both workable and cohesive to pass through the pump without blockage.
- Workable mixtures containing relatively small coarse aggregate particles tend to provide an easily placed and dense concrete.
- Concrete can be transferred from a barge directly into the forms.
- Pumped concrete fills forms from the bottom upwards, displacing the seawater as additional concrete is added.

Restrictions/Cautions: See CPM-5, Tremie Concrete. Also:

a. Carefully control slump of concrete to 6 to 8 inches.
b. Avoid inclines in the pipe whenever possible.
c. If delays are encountered, move concrete several feet every 5 minutes. If concrete becomes stiff due to a long delay, discard the mix. Do not retemper by adding water.
d. Use rubber hose only for discharge end and short pumping distances.

Preparation: Preparation of the repair location is the same as for cast-in-place concrete. Also, carefully plan location of pump and routing of pipeline to minimize moves. The pipeline should be horizontal or vertical whenever possible.

Bonding: Not usually required underwater; for above water, see CPM-3.

Concrete Mix:

a. A typical mix proportion is 1:3:1 by weight with a water-cement ratio of 0.45.
b. Use rounded coarse (3/8-inch minimum) aggregate when possible.
c. Sand should have a higher proportion of finer sizes.
d. Avoid porous aggregates such as expanded clay, foamed slag, and pumice.

Placement: The principles of placing tremie concrete apply. Also:

a. Before filling hopper, lubricate the pipe with water, then a cement-water slurry.
b. Take all precautions to avoid separation of the mix.
c. Always keep discharge buried in the fresh concrete.
d. Control discharge to keep lateral flow of concrete within 2 to 3 feet.

Curing: Not applicable underwater. Same as cast-in-place above water.

CPM-7: PREPACKED CONCRETE

Description: This method entails placing coarse aggregate in the form and filling the voids with grout. It is used on large repair jobs, and usually grout is pumped through grout pipes from the bottom up.

Uses: Prepacked concrete is used where placement of cast-in-place concrete is not practical. It is also used underwater where the tremie or pumped methods are not practical due to inaccessibility. It is suitable for vertical surface repairs that have a minimum thickness of 3 to 4 inches.

Restrictions/Cautions:

a. Prior to injecting grout, be sure fines have not collected in the coarse aggregate. Fines in the aggregate can impede the flow of grout and create voids.

b. Protect the aggregate from contamination after it is placed.

Preparation: Preparation of the repair location is the same as for cast-in-place concrete. Also, ensure grout pipes are well installed and fixed to forms or reinforcing. A vent must be provided at the highest point.

Bonding: Not required.

Concrete Mix: Coarse aggregate is sized to the size of repair. The sand-cement grout is usually richer than a 1:1 mix. Admixtures are used as required by the circumstances. Usually, a chemical admixture is used as an intrusion aid for the grout. This suspends solids and provides fluidity. An air-entraining admixture is used to obtain about 9 percent air in the grout.

Placement: Pump the grout soon after the aggregate is placed. Ensure that all voids are filled and that segregation in layers does not take place. When forms are filled, apply a closing pressure of about 10 psi to drive out air and water through the vent.

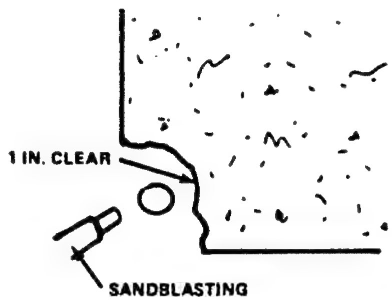
Curing: Same as cast-in-place concrete.

7.4 CONCRETE REPAIR PROCEDURES. Figure 7-1 summarizes the general steps to be taken in concrete repairs. The more standard repair procedures and techniques used for waterfront facilities are listed in table 7-1 and included in the following pages. These repair techniques should be utilized in conjunction with the guidelines for concrete in paragraph 7.1, the descriptions of methods of placement in 7.3, and the preservation measures outlined in chapter 3.

Table 7-1. Repair Techniques for Concrete Structures.

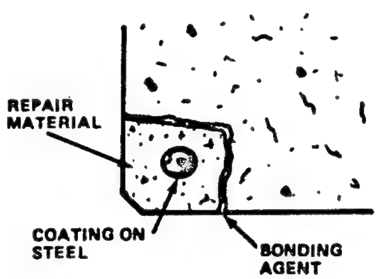
No.	Description
CR-1	Repair Small to Medium Cracks by Epoxy Grout Injection
CR-2	Major Joint and Crack Repair
CR-3	Repairs to Concrete Seawall
CR-4	Miscellaneous Repairs to Concrete Piles
CR-5	Concrete Jacketing of Concrete Piles
CR-6	Typical Combination Repair: Cast-in-Place Concrete and Epoxy Grout Injection
CR-7	Typical Repair Using Polymer Concrete
CR-8	Typical Concrete Wall Repair

REPAIR CONCRETE STRUCTURES



SURFACE PREPARATION

- Remove all deteriorated and loose concrete.
- Expose all uncovered reinforcing steel at least 1 inch clear all around.
- Sandblast/waterblast/wire brush concrete and steel as necessary to clean thoroughly.
- Keep concrete surface wet for several hours.
- Coat reinforcing steel with grout or epoxy resin.
- Just before placing repair material, apply bonding agent to old concrete.

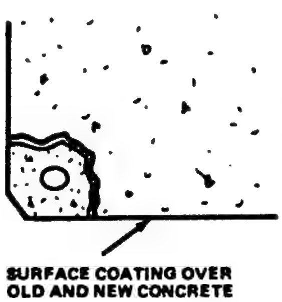


PLACE REPAIR MATERIAL

- Bonding agent must be wet or tacky.
- Depending on size and type of repair, material may be a mortar or concrete; portland cement concrete, latex modified concrete, or epoxy concrete.
- Above water placement; hand placement, dry pack, cast-in-place, or shotcrete.
- Underwater placement; tremie, pumped, or prepacked.

CURING

- Use most efficient moist-curing for minimum of 7 days if practicable.
- Use curing compound if necessary.



SUFACE COATING

- Determine if surface coating is required.
- Prepare surface by air/abrasive blasting.
- Apply coating applicable to location, exposure, and use of concrete.

Figure 7-1. General Steps to Concrete Repair.

CR-1: REPAIR SMALL TO MEDIUM CRACKS BY EPOXY GROUT INJECTION

Problem: Cracks caused by weathering, deterioration, or reinforcing steel corrosion allow water to penetrate the structure.

Description of Repairs: Filling and sealing small to medium cracks by injecting a low-viscosity epoxy resin and sealing the outside with an epoxy paste. Routing and cleaning of cracks are performed with conventional hand and power tools. Injection of the epoxy for smaller jobs can be done with a hand-operated caulking gun. Large jobs are usually done with special epoxy pumps, operating at less than 150 psi, with mixing tank, injection hose, and controls.

Materials:

a. Low-Viscosity Epoxy - Select an epoxy resin suitable for wet surfaces and underwater application that is compatible with crack volume, the existing concrete, and equipment to be used for injection. See section 3.2.5.2.

b. Sealing Epoxy - Use a quick-setting epoxy paste adhesive suitable for underwater application that has good bonding characteristics for concrete being repaired.

Preparation:

a. Rout out cracks to remove all deteriorated and loose concrete and aggregate. Clean area to receive sealing epoxy with wire brush, high pressure water jet, or sandblasting.

b. For larger job with deep cracks, drill injection holes every 6 inches along the length of the crack. Install a tube or one-way polyethylene valve in the holes as injection ports.

c. For small and shallow cracks to be repaired with a hand gun, injection ports may be openings left in the sealing epoxy every 6 inches.

Repair Procedures: See figure 7-2.

a. Perform repairs when ambient/water temperature is at least 50°F.

b. Seal the outside surface of the crack with the epoxy paste, carefully sealing around the injection ports.

c. After the surface seal has set, the low-viscosity epoxy grout is injected, starting at the bottom port for a vertical crack. Continue injection until epoxy shows in the next port, then continue up the crack until the entire crack is filled.

d. Plug the port holes with the sealing epoxy paste.

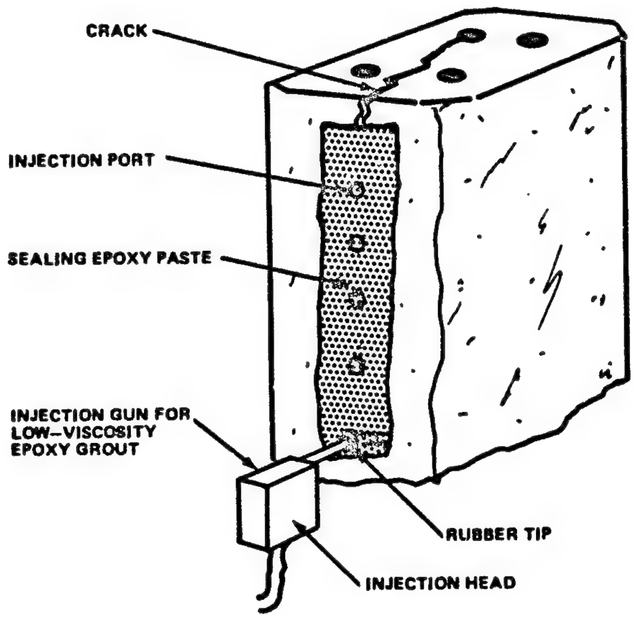


Figure 7-2. Typical Crack Repair with Epoxy Grout Injection.

CR-2: MAJOR JOINT AND CRACK REPAIR

Problem: Large cracks or construction joints are open allowing water to penetrate in or leak through the structure.

Description of Repairs: Sealing of cracks and construction joints to prevent leakage. This repair is performed after grouting of cracks is completed. Example given is for drainage and discharge tunnels, and should be modified for less demanding applications. Repair requires conventional hand and power tools and a heating bucket.

Materials:

a. Sealant No. 1 - two component epoxy coating system. See section 3.2.5.2.

b. Sealant No. 2 - non-meltable mastic of refined asphalts, resins, and plasticized compounds reinforced with nonasbestos fiber. Resistant to seawater, salts, acids and dilute alkalis.

c. Primer for Sealant No. 2 - Asphaltic liquid primer compatible with sealant.

d. Sealant No. 3 - Two component, moisture insensitive epoxy resin mortar; 1 part mixed epoxy to 1 part 30/40 aggregate by volume.

e. Copper plate - 16 gauge conforming to ASTM B 370.

Preparation: Chip out and saw cut concrete as shown on figure 7-3. Clean all surfaces to receive sealants of all loose and deteriorated concrete and marine growth by chipping, scraping and sandblasting. Provide clean, sound bond surfaces. Prepare surfaces to meet sealant manufacturer's requirements.

Repair Procedures:

a. Perform repairs when ambient or water temperature is at least 50°F, depending on whether structure is exposed or submerged.

b. Sealant No. 1 - apply with brush to cleaned surfaces.

c. Prime all surfaces to receive sealant No. 2 with primer and let dry.

d. Sealant No. 2 - Heat sealant. Apply 3 layers as shown in figure 7-3. Pound each layer during and after cooling.

e. Fasten copper strip in place for placement of sealant No. 3. Do not use fasteners of dissimilar metal.

f. Apply sealant No. 3 as shown and tool the joint as required.

Curing: Cure sealants per manufacturer's specifications.

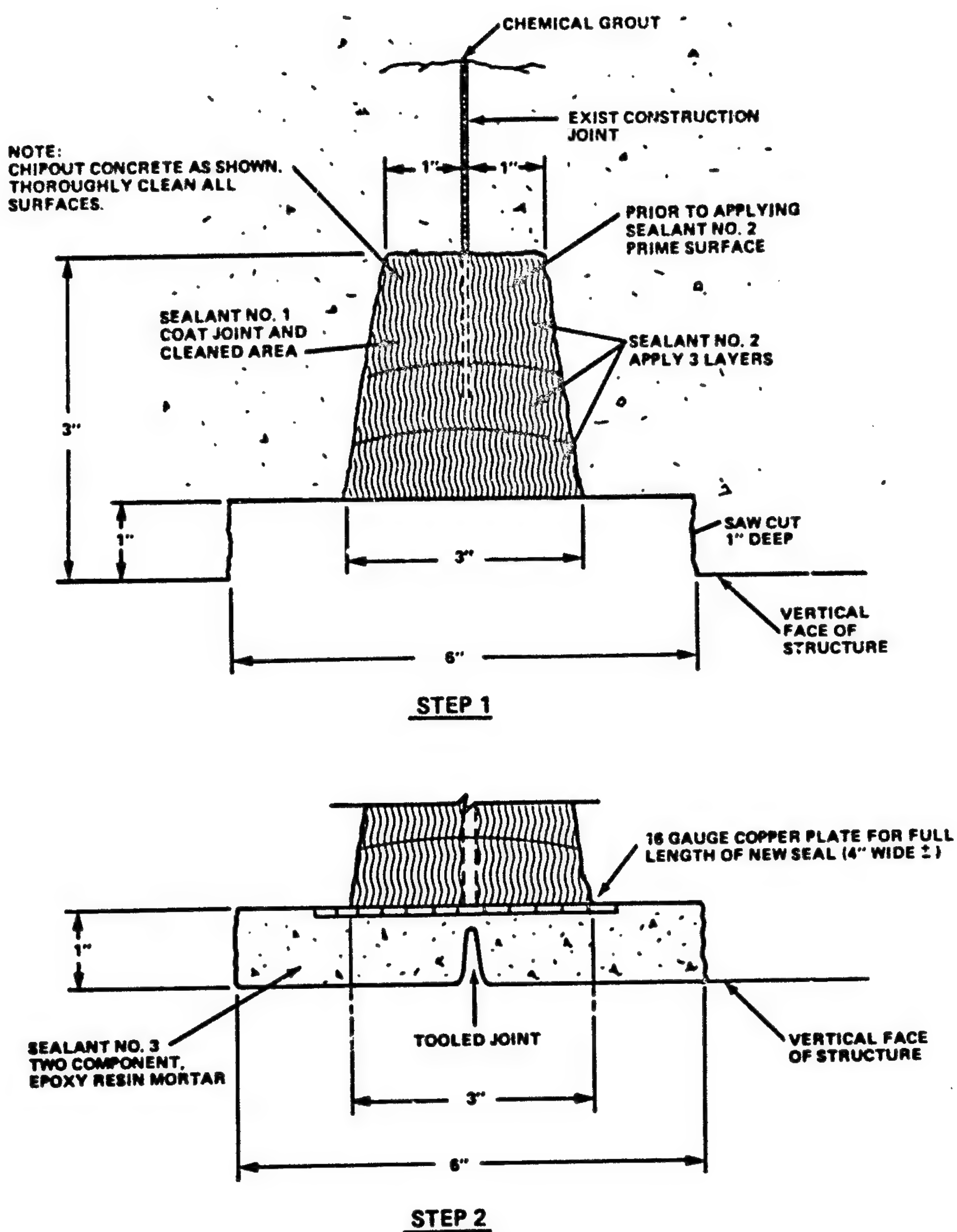


Figure 7-3. Joint and Crack Repair.

CR-3: REPAIRS TO CONCRETE SEAWALL
(Extracted from reference 7)

Problem: Sulphate attack has caused limited disintegration of the seawall within the tidal zone.

Description of Repairs: Contact between the existing concrete and seawater is eliminated by adding a repair layer of sulphate-resisting concrete. Old concrete is replaced only to the extent necessary to repair damage and to isolate the old concrete from the seawater reaction. See figure 7-4.

Repair procedures are as described in CPM-3 for cast-in-place concrete, or CPM-5 if the tremie method is required. Also, see repair CR-8 for certain applicable procedures.

- **Type "A" Repair:** In this case, a minimum of 8 inches of the existing wall thickness must be sound concrete. A facia of new concrete is added, well anchored to the existing wall.
- **Type "B" Repair:** In this case, a section of the wall is replaced, through its entire width, which includes the facia on the water side. This type uses the dry pack method, CPM-2, to close the gap between the top of the new concrete and the existing concrete. See repair CR-8 and figure 7-7 for a somewhat similar wall repair.

Application: These types of repair are applicable where the extent of the deterioration is limited and is not threatening to the entire height of the seawall, and a partial repair from foundation to above high water will solve the problem. The wall foundation must be in good condition. Extensive deterioration along a length of the seawall would call for a complete demolition and replacement of a section of wall.

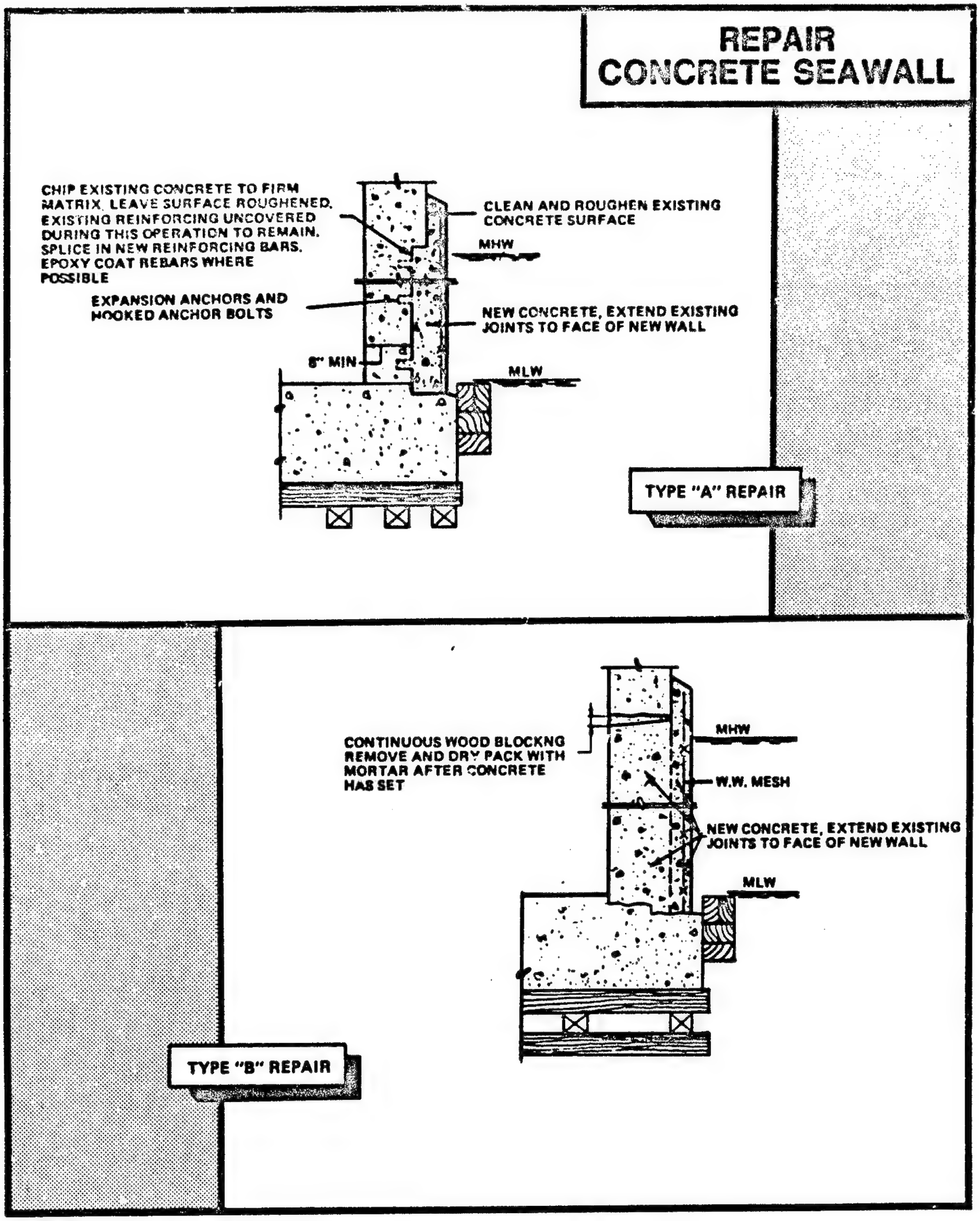


Figure 7-4. Repairs to Concrete Seawall.
(Extracted from reference 7)

CR-4: MISCELLANEOUS REPAIRS TO CONCRETE PILES

Problem: Concrete pile is worn from abrasion at waterline; has spalled areas above the tidal zone; or has a significant crack.

Description of Repairs: In all cases, the repair area must be cleaned thoroughly of marine growth. All loose and deteriorated concrete must be removed. If reinforcing steel is exposed, it must be cleaned of all rust and scale and exposed at least 1 inch clear all around. Epoxy coat reinforcing steel if above mean low water.

Figure 7-5 illustrates the following:

- **Concrete Jacketing:**

  a. Wrap pile with spiral reinforcing length of jacket.
  b. Place form around pile (metal, fiberglass, fiber, or other material).
  c. Fill form with 5000 psi concrete, either pumped or placed with a tremie (see CPM-5 and CPM-6).
  d. Form may be removed or left in place.

- **Patch Spalled Areas:**

  a. Select an epoxy compound suitable for wet applications. For deep repairs, use cement and sand fillers with the epoxy.
  b. Repair the spalled areas by hand (see CPM-1).

- **Fill Crack with Epoxy Grout:** See repair CR-1.

Applications: The concrete jacketing repair is a partial restoration when the pile is worn/deteriorated only in the tidal zone and sound below and above. See repair CR-5 for more complete concrete pile restoration.

The spall patching and crack filling repairs are relatively minor, inexpensive techniques to protect the reinforcing steel from seawater. The effectiveness of the spall patches is dependent upon the bond that is obtained with the old concrete.

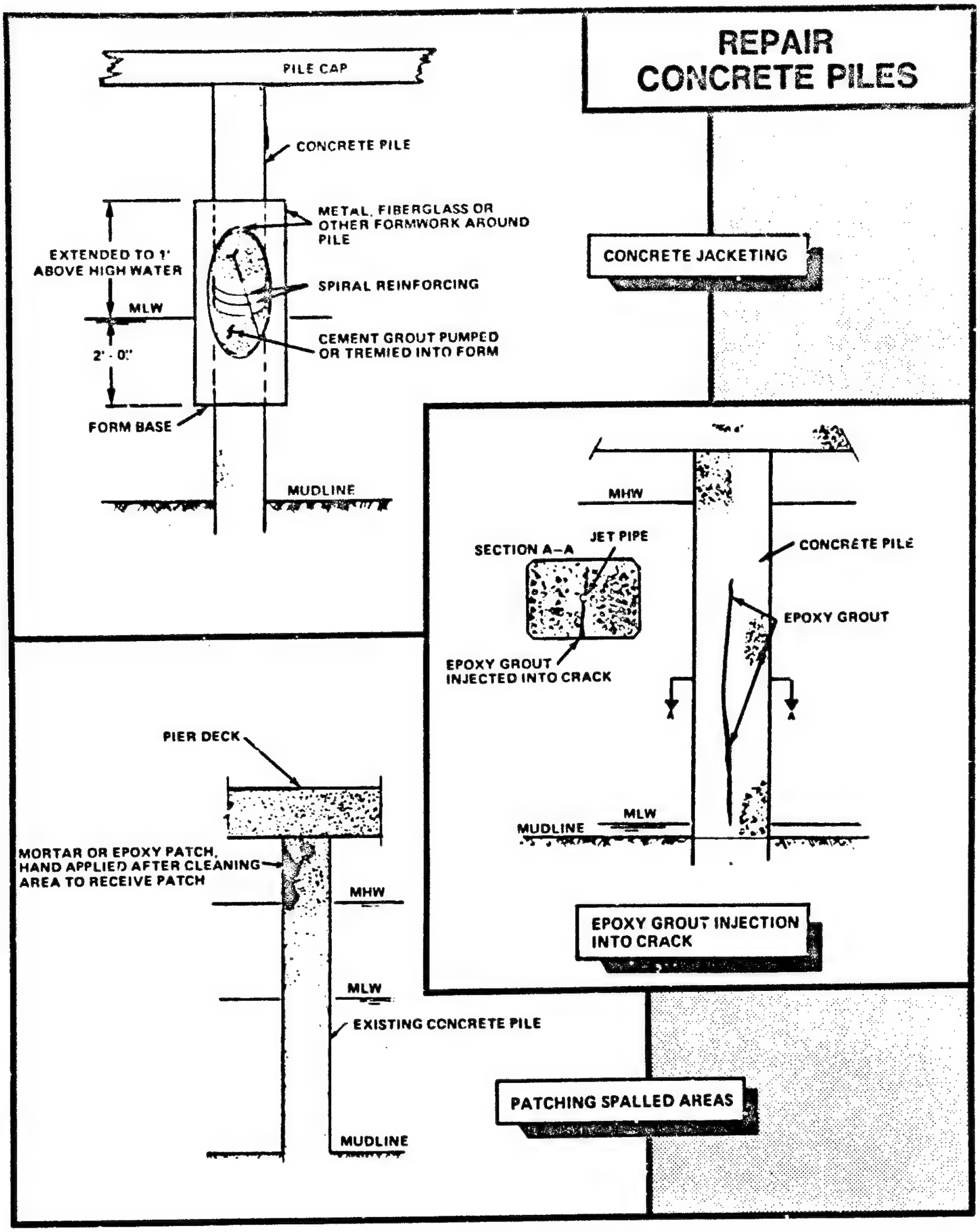


Figure 7-5. Miscellaneous Repairs to Concrete Piles.

CR-5: CONCRETE JACKETING OF CONCRETE PILE
(Extracted from reference 7)

Problem: Precast concrete piles have major deterioration due to sulphate attack. Deterioration extends to the mud line.

Description of Repairs: See figure 7-6. In this example, the original pile section was 16 inches square. The concrete jacket, as shown, is 30 inches in diameter. A timber encasement, with galvanized steel bands, is used in the tidal zone. A corrugated sheet metal form is used down below the mud line. See CPM-6 for the pumped concrete method of injecting the new concrete. Figure 7-6 shows the top portion of the pile encased with either a pneumatically-piaced (CPM-4) or hand-placed grout (CPM-1).

Applications: This method is applicable when the remaining section of pile is structurally sound and judged to be worth saving. Jacketing versus complete replacement is an economic decision.

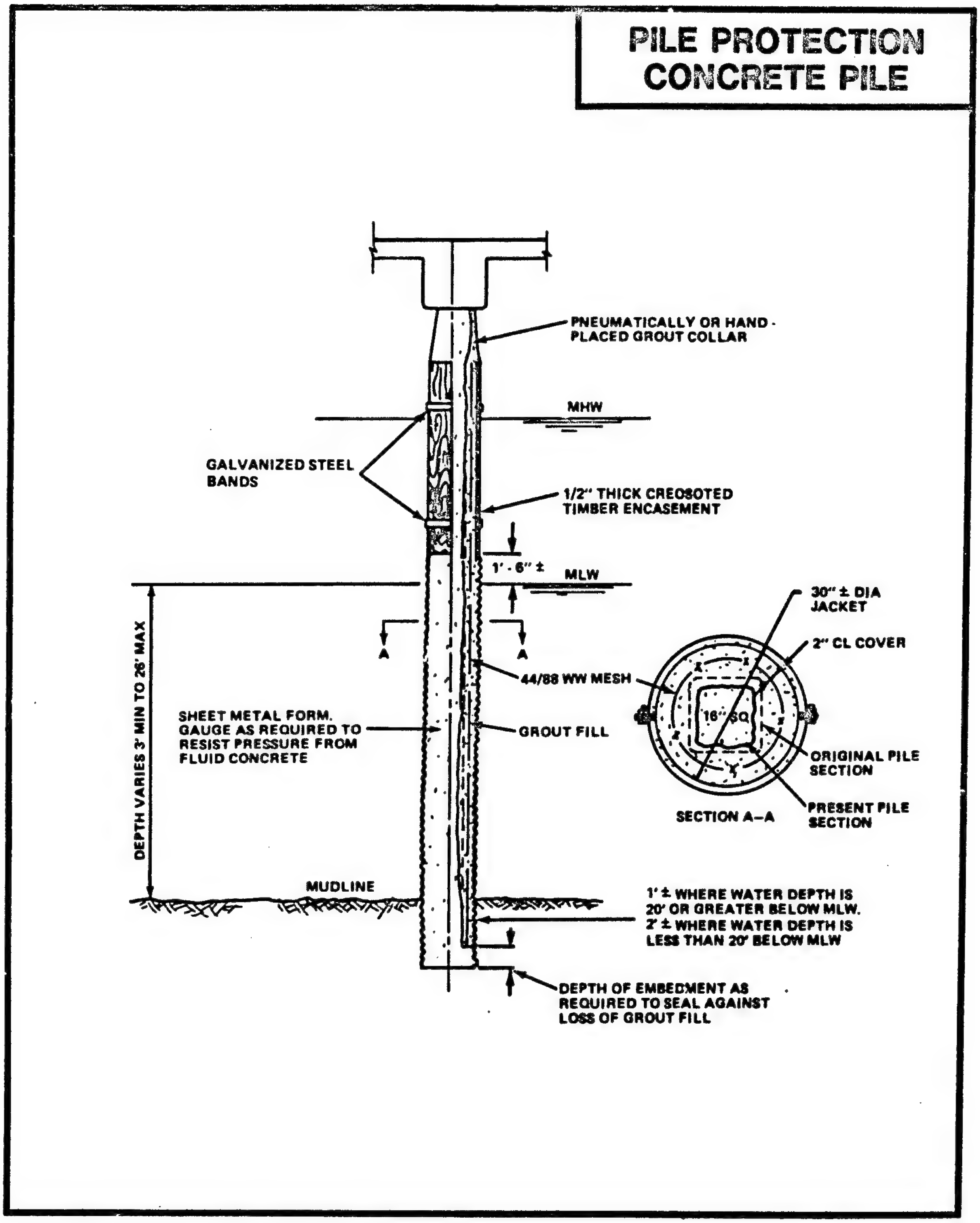


Figure 7-6. Concrete Jacketing of Concrete Pile (Extracted from reference 7).

CR-6: TYPICAL COMBINATION REPAIR
CAST-IN-PLACE CONCRETE AND EPOXY GROUT INJECTION

Problem: Concrete footings containing many cracks with some spalling, scaling, and delaminated areas.

Description of Repairs: Repair footings using a combination of restoration with portland cement concrete, and filling cracks and delaminated concrete by injection of epoxy resin. Requires air hammer, conventional hand and power tools, and injection gun or pump for epoxy.

Materials:

a. Portland cement concrete.

b. Epoxy resin bonding agent.

c. Low-viscosity epoxy resin for injection. Both epoxies meeting ASTM C 881.

Preparation:

a. Remove all unsound concrete.

b. Wire brush or sandblast all surfaces to receive bonding agent and clean thoroughly.

c. Thoroughly clean and coat any exposed reinforcing steel.

d. Sound concrete with metal rod to determine extent of delamination and outline the areas.

e. After restoration of concrete is completed, rout and clean cracks to be filled with injected epoxy.

Repair Procedures:

a. Place, cure, and finish concrete repairs to restore structure to its original shape (CPM-3).

b. Select epoxy injection points and drill holes if required. Insert injection tubes or valves if required. See repair CR-1.

c. Fill cracks 0.003 inches wide and larger, and delaminated areas, by injecting the low-viscosity epoxy. For larger jobs with significant areas of delamination and deep cracks, pressures up to 500 psi may be required.

d. Plug the injection holes with epoxy paste.

CR-7: TYPICAL REPAIR USING POLYMER CONCRETE

Problem: Concrete roof deck spalling due to corrosion of reinforcing steel and cracks around support columns. General cracking and weathering due to age.

Description of Repairs: Patch spalled areas with polyester mortar. Coat roof deck with polyester concrete. Reseal joints with polyurethane joint sealer. Requires conventional hand and power tools. May not be suitable for vehicle traffic areas.

Materials:

a. Commercial polyester patching mortar.

b. Neat polyester resin for bonding coat.

c. Commercial mix of polyester concrete.

d. Polyurethane joint sealant meeting Federal Specification TT-S-0230.

Preparation:

a. Remove all unsound concrete in the spalled areas. Expose reinforcing steel all around.

b. Clean the exposed reinforcing steel, and entire deck area by sandblasting.

c. Thoroughly clean areas to receive new material immediately prior to placement.

Repair Procedures:

a. Patch spalled areas with polyester mortar.

b. Seal entire deck area with neat polyester resin.

c. Cover the deck area with a thin coating of polyester concrete. Use minimum of 1/2 inch. Thickness used must consider weight added to deck and its load-bearing capacity.

d. Remove all joint sealant and reseal joints.

CR-8: TYPICAL CONCRETE WALL REPAIR

Problem: Holes or severely deteriorated areas require replacement of wall section with cast-in-place concrete.

Description of Repairs: Defective section of wall is removed, surfaces and reinforcing steel are prepared, formwork constructed, and wall is restored with cast-in-place concrete. Repair may be an internal section, as shown in figure 7-7, or it may be the top of a wall or pier deck curb requiring an open-top form. Equipment used includes sandblasting and air-water jet cleaning equipment, concrete saw, air chipping hammer, air-suction gun for mortar if available, power vibrator and tamper, and conventional concrete placement tools.

Materials: Sand-cement mortar and portland cement concrete.

Preparation:

a. Use air hammer or hand methods to remove all unsound concrete to the limits of the repair area.

b. Cut the top edge of the hole at the face of the structure to a fairly horizontal line (see figure 7-7). Where a hole passes through a structural element, it may be necessary to fill the hole from both sides. In this case the slope of the top of the cut should be modified accordingly.

c. Cut the bottom and sides of the hole sharp and approximately square with the face of the wall. When the hole goes entirely through the concrete section, spalling and featheredges can be avoided by having chippers work from both faces. All interior corners should be rounded to a minimum radius of 1 inch.

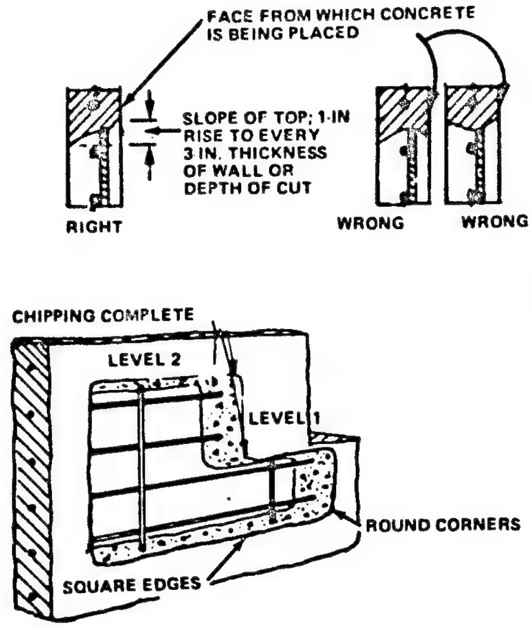
d. Do not leave reinforcing steel partially embedded. Ensure there is a minimum of 1 inch clearance around each exposed bar. Remove unnecessary tie wires.

e. Clean all surfaces to bond to new concrete with wet sandblasting and air-water jet. Clean exposed steel with abrasive blasting or wire brushing. Epoxy coat steel where possible.

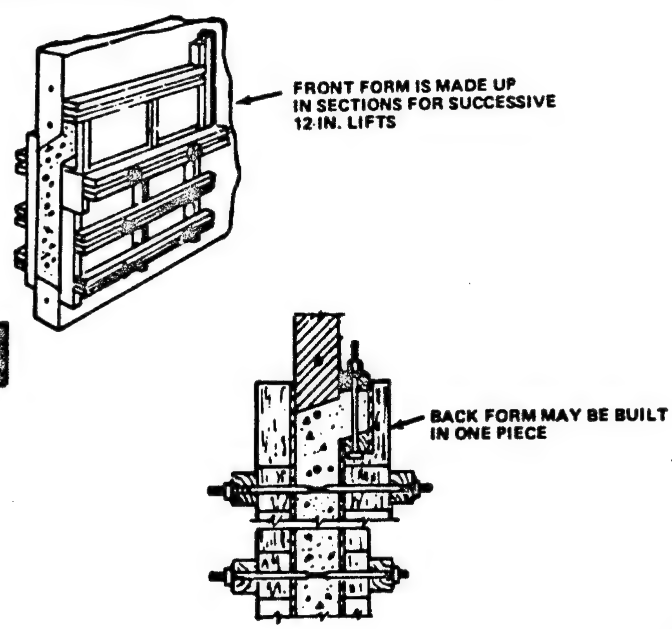
Repair Procedures:

a. Construct front forms for patches more than 18 inches high in horizontal sections so the concrete can be placed in lifts not more than 12 inches high. The back form can be built in one piece. Sections to be set as concreting progresses should be fitted before concrete placement is started. See figure 7-7.

REPAIR CONCRETE WALL



PREPARATION OF IRREGULAR AREA FOR TYPICAL WALL REPAIR



FORMWORK FOR TYPICAL WALL REPAIR

Figure 7-7. Typical Concrete Wall Repair.

CR-8: TYPICAL CONCRETE WALL REPAIR (Continued)

b. For irregularly shaped holes, chimneys (accesses) may be required at more than one level. In some cases, such as when beam connections are involved, a chimney may be necessary on both sides of the wall or beam. In all cases the chimney should extend the full width of the hole.

c. Ensure forms are substantially constructed so that pressure can be applied to the chimney cap at the proper time.

d. Ensure forms are mortartight at all joints between adjacent sections, between the forms and concrete, and at the tie-bolt holes to prevent the loss of mortar when pressure is applied to the concrete during the final states of placement. Twisted or stranded caulking cotton, folded canvas strips, or similar material should be placed between the joints as the forms are assembled.

e. Surfaces to receive new concrete should be kept wet for several hours, preferably overnight, immediately prior to placement.

f. Immediately before placing the front section of form for each lift, coat the surface of the old concrete with a 1/8-inch-thick layer of mortar. This mortar should have the same sand and cement content and the same water-cement ratio as the new concrete. The surface should be damp, but not wet. The mortar can be applied with an air-suction gun, by brushing, or being rubbed into the surface by hand encased in a rubber glove.

g. Place concrete immediately. Ensure thorough compaction by vibration and/or power tamping.

h. Forms may usually be removed the day after placement. If chimneys were used, remove the remaining projections the second day working up from the bottom.

i. Thoroughly moist-cure the new concrete.

j. Finish with a wood float finish. Tool or chamfer edges and corners as required. Avoid using water in finishing.

CHAPTER 8. REPAIR OF STEEL STRUCTURES

8.1 GENERAL. Steel is used extensively in construction and repair of waterfront facilities due to availability, cost, ease of fabrication, physical and mechanical properties, and the design experience with its use. Structural steel and cast or fabricated steel are used in all are of the waterfront. Typical applications requiring maintenance include:

- Piers, wharves, bulkheads, and quaywalls utilizing steel H-piles or pipe piles to support or brace the structure; steel sheet piling used to retain fill; structural steel shapes used for framing.

- Fender systems incorporating steel H-piles.

- Mooring hardware such as cleats, bollards, bitts, and chocks made from cast or fabricated steel.

- Other items such as utility lines, grating, opening frames, space manhole covers, fences, bolts and nuts, handrails, and concrete reinforcement.

- Steel components of camels.

Corrosion is the major cause of deterioration of steel structures and components. The extent or severity of corrosion will vary with the exposure zone of the material; that is, whether it is in the atmospheric zone, the splash or tidal zone, or the submerged zone. Selection of the repair technique must consider each of these varied conditions and such other elements as:

- Facility mission and required life.

- Extent of damage and deterioration.

- Estimated iife expectancy with repairs and without repairs.

- Projected load capacities.

- Problems associated with mobilization of equipment, personnel, and materials to accomplish repairs/maintenance.

- Tides and currents

- Economics and trade-offs.

Maintenance and repair of steel structures and components will fall into five general categories: coating and wrapping, cathodic protection, concrete encasement, partial replacement, and complete replacement.

8.2 REFERENCES. Materials used to develop repair techniques and planning factors outlined in this chapter, have been taken, in part, from the following documents:

- NCEL TM-43-85-01 O&M, UCT Conventional Inspection and Repair Techniques Manual, October 1984 (reference 36)
- NAVDOCKS MO-306, Corrosion Prevention and Control, Naval Facilities Engineering Command, Washington D.C., June 1964 (reference 38)
- CEL CR 81.009, Survey of Techniques for Underwater Maintenance/Repair of Waterfront Structures, Childs Engineering Corp., April 1981 (reference 39)

8.3 PLANNING THE REPAIRS. Accomplishment of repairs to steel structures will frequently be controlled by the availability of skilled personnel and equipment. In many cases, structural repairs, particularly of bearing piles and sheet piling, will be accomplished by contract.

The initial planning step to establishing the repair approach must involve review of prior inspection reports to determine the scope of damage and/or deterioration, the rate of deterioration, and specific operational constraints placed upon the facilities because of the deterioration. Once the scope of repair requirements, including priorities, is established, the method of accomplishment must be determined, whether in-house or by contract.

8.3.1 Special Skill Requirements: Repairs to the pier decking and curbs, pile caps, fender system and deck hardware will normally cover skills common to in-house shop forces. Underwater repairs require special skill levels that may not be available with in-house forces. These include the general diving capability plus knowledge of: removal of marine growth; jetting or air lifting procedures; underwater cutting, welding and drilling techniques; underwater lifting procedures; application techniques for underwater protection coatings; techniques for underwater placement of epoxy mastic patches; and jacketing and wrapping materials used in underwater construction.

8.3.2 Equipment Requirements: Repairs to the pier decking and curbs, pile caps, fender system and deck hardware will generally require equipment common to in-house shop forces. Equipment for bearing or sheet piling repairs, however, may include: high-pressure water blaster, hydraulic grinders with barnacle buster attachment, hydraulic drill with bits, hydraulic power unit, oxygen arc cutting and/or oxy-acetylene torch equipment, protective clothing and gloves for personnel handling epoxy coatings for steel, concrete pump with hose, jetting pump and hose, rigging equipment, float stage and scaffolding, cofferdams, clamping template for cutting piles, special clamping equipment, and crane.

8.4 REPAIR PROCEDURES: Repair techniques for waterfront steel structures are summarized in table 8-1. Selection of a technique must address both immediate repairs necessary to restore the structure to full (or other designated) usage and protective measures needed to prevent further corrosion. Selection of means for restoring the structural capacity of the facility may be straightforward, being generally controlled by the level and rate of deterioration. Decisions on the level of protection to provide to inhibit corrosion in the future may be more difficult. Generally, these decisions are economically driven.

Each repair decision must carefully weigh the long term operational requirements and existing environmental factors (tides and currents) that can help accelerate corrosion prior to evaluating initial and life cycle costs. In many cases, including a combination of cathodic protection and protective coating in the repair decision may be the most cost effective in the Long term. Usage of any of the repair techniques which follow should fully adhere to the preservation treatment requirements outlined for steel structures in chapter 3.

After all members have been fastened or placed, bolt heads, washers, and nuts shall be given one full coat of petrolatum (grease) coating conforming to Federal Specification VV-P-236. All surfaces to be coated shall first be thoroughly cleaned and dried, and all nuts shall be drawn tight.

Table 8-1. Repair Techniques for Steel Structures

NO.	DESCRIPTION
Bearing Piles	
SR-1	Protecting Steel Pile by Coating or Wrapping
SR-2	Cathodic Protection for Steel Bearing Piles
SR-3	Partial Replacement of Steel Pile
SR-4	Repairing Steel Pile with Concrete Encasement
SR-5	Complete Replacement of Steel Pile
Sheet Piling Walls	
SR-6	Coating/Cathodic Protection for Steel Sheet Pile Wall
SR-7	Patching of Steel Sheet Pile Wall
SR-8	Reinforcing Tie-Back Systems for Steel Sheet Pile Wall
SR-9	Replacement of Existing Steel Sheet Pile Wall
SR-10	Installing a Concrete Cap/Face on a Steel Sheet Pile Wall
SR-11	Scour Protection for Steel Pile Supported Waterfront Structure

SR-1: PROTECTING STEEL PILES BY COATING OR JACKETING

Problem: A new steel pile has been installed or an existing pile has experienced slight deterioration (less than 15 percent) of the cross-sectional area at some point. Protection against further corrosion is required.

Description of Repairs: Clean steel above water with abrasive blasting equipment and underwater with water jet cleaning equipment.

Epoxy-Polyamide Coating: Mix contents of two separate packages (epoxy-resin base and viscous polyamide) to form a hardened mass. All coatings, should be mixed and applied in accordance with manufacturer's instructions. Ambient temperature of about 70°F is desirable. Apply by smearing by hand over surface to a thickness of 1/8-inch to 1/4-inch (figure 8-1).

Fiberglass Jacket: Place jacketing around pile and secure. Pour epoxy grout inside sleeve if grout is to be used. Seal top and bottom to restrict water inside jacket, if mortar is not to be placed between pile and jacket (figure 8-1).

Concrete Jacket: During installation of steel pile, place concrete pipe jacket around pile after it is driven. Fill the annular space between concrete jacket and pile with concrete (figure 8-1). The pile must be accessible from the top.

Application: These methods can be used to prevent further rusting. Economics will govern the selection based upon the extent of overall facility deterioration, access to pile, and availability of alternatives.

Future Inspection Requirement: Increased inspection may be required, particularly in areas where ice may be present, to detect signs of abrasion of the mastic or jacketing and renewed corrosion of the pile.

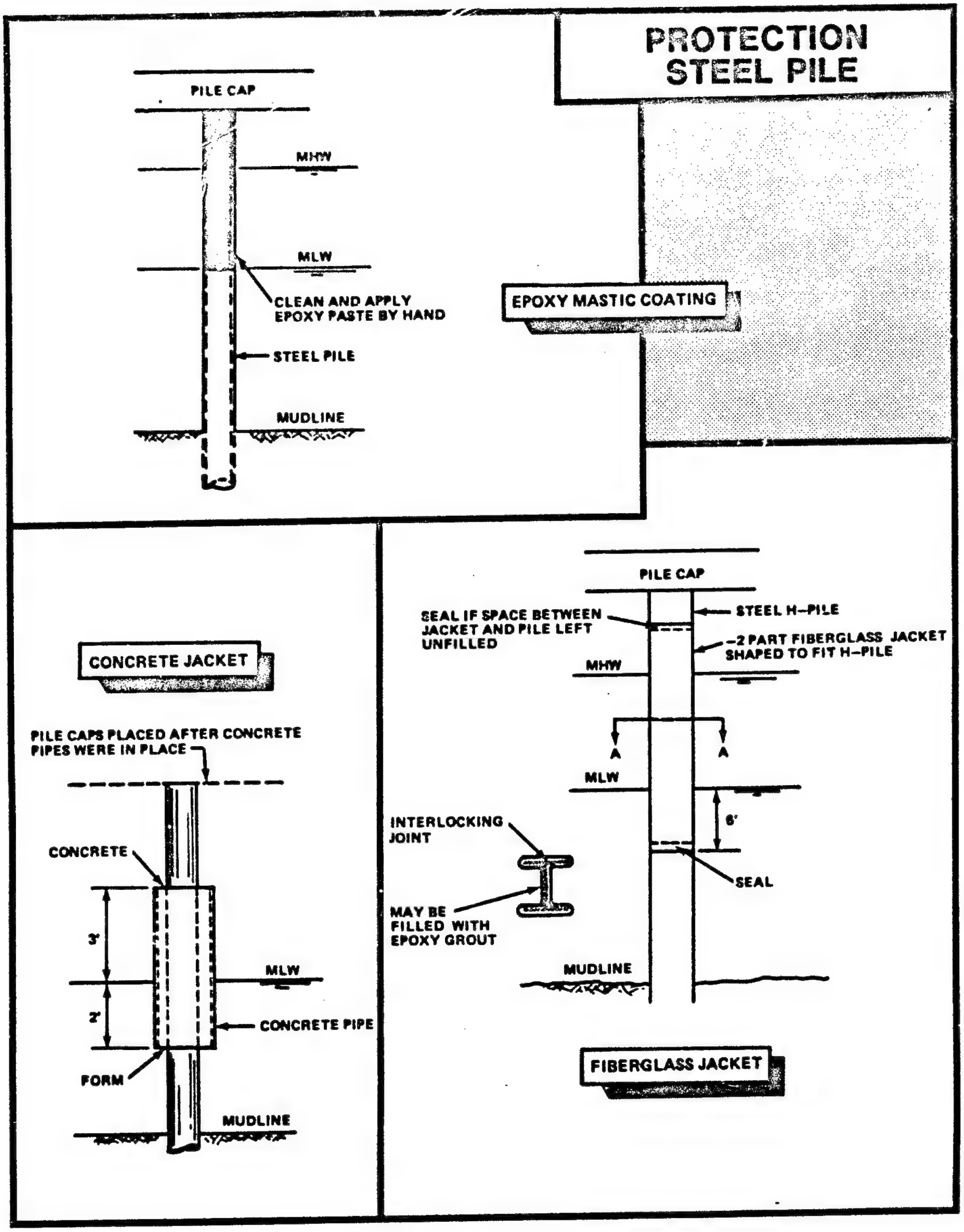


Figure 8-1. Protecting Steel Piles by Coating or Jacketing.

SR-2: CATHODIC PROTECTION FOR STEEL BEARING PILES

Problem: New steel bearing piles have been installed or existing piles have experienced slight surface deterioration. Anticipated corrosion is high. Protection against further corrosion is required.

Description of Repairs: Two methods are available for providing cathodic protection for steel bearing piles:

> **Sacrificial Anode System:** Secure sacrificial anodes below low water on steel by welding or bolting. Size, type and spacing of anodes must be determined to suit structure and environment (figure 8-2). Positive electrical connection between elements must be maintained.
>
> **Impressed Current System:** Install the cathodic protection system as shown in figure 8-2. Basic components include:
>
> a. Anode: material to be consumed over a long period of time.
> b. Electrical potential: power source (rectifier) to provide constant electrical potential between anode and steel pile.
> c. Ground between piles and power source to provide closed cell.

Application: Requires careful design and installation. System is not effective for mitigating corrosion above mean low water.

Future Inspection Requirements: The cathodic protection system must be carefully monitored and maintained. If anodes for an impressed current system are placed between bents, special inspections must be made to ensure that floating debris has not damaged or removed the individual anodes.

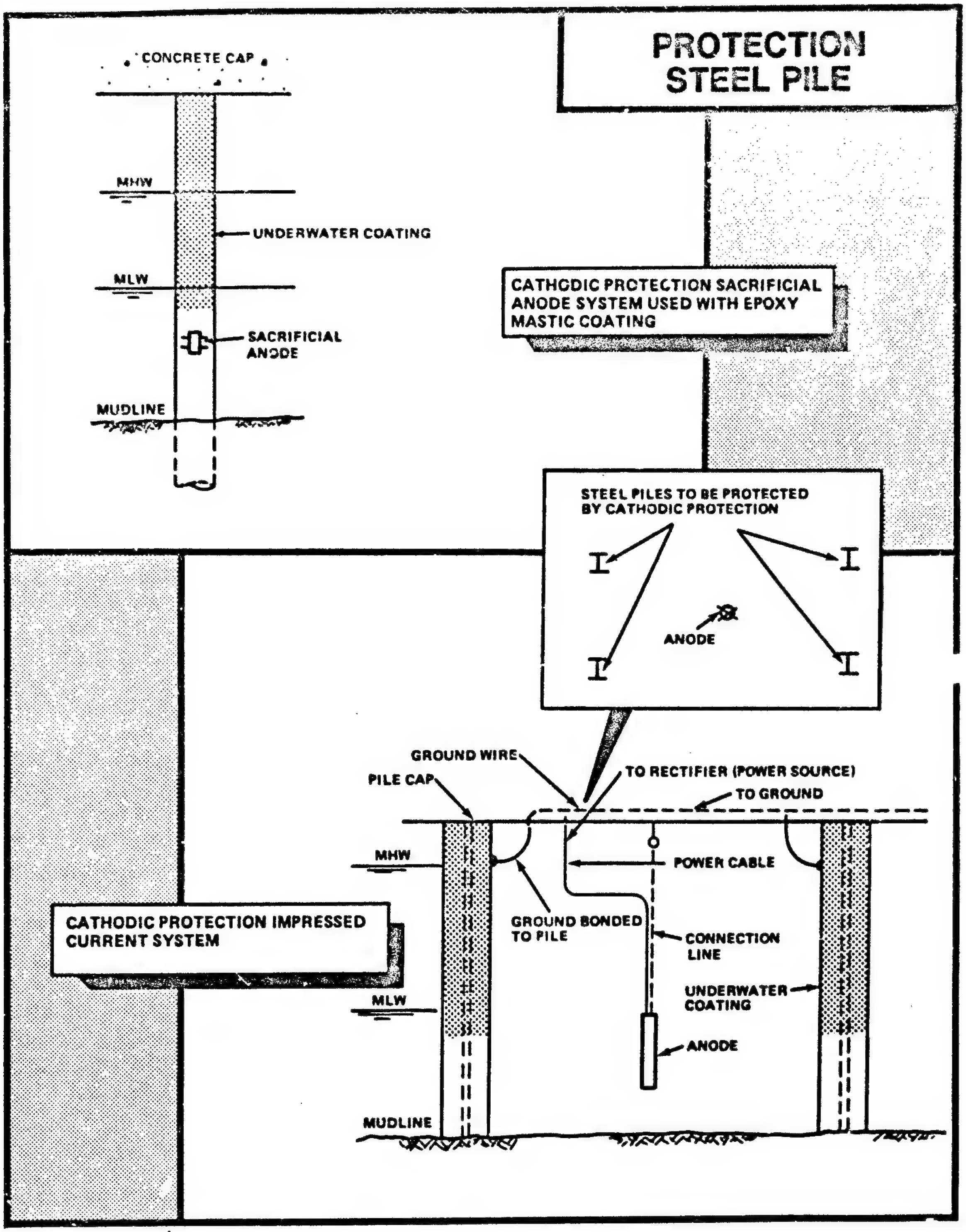


Figure 8-2. Cathodic Protection For Steel Bearing Piles.

SR-3: PARTIAL REPLACEMENT OF STEEL PILE

Problem: Moderate to heavy deterioration (greater than 35 percent) of the upper cross-sectional area of the H-pile has occurred.

Description of Repairs: Cut out the corroded section of pile being sure that the bottom cut and top cut (if applicable) are square. Temporary supports may have to be provided to transfer the load from the pile being repaired to adjacent piles. Fabricate a welded assembly consisting of a 1-inch steel bearing plate, two 3/8-inch steel side plates, and four steel angles, and place over the bottom cut. Drill and bolt the bearing assembly to the remaining lower steel pile using 1-1/4-inch galvanized steel bolts. Add cathodic protection to new section.

For Intermediate Replacement: (figure 8-3), cut a section of new H-pile to fit the missing length of pile and weld a 1-inch steel bottom bearing plate to the new section. Place the intermediate section into position and bolt the bearing plates together. Weld the upper joint and four 5/8-inch steel splice plates to both old upper and new H-pile sections.

For Total Upper Section Replacement: (figure 8-3), cut a new section similar to that required for intermediate replacement, except cut to fit under the concrete cap using a 1-inch steel bearing plate bolted to the cap. This arrangement is necessary when the steel has corroded extensively at the concrete-steel interface.

All new metal should be cleaned and coated before installation. Welded joints should be cleaned and coated after welding. All welded joints should be watertight.

Application: This method restores the structural strength lost in the deteriorated upper section. Corrosion can again occur once the coating fails. Economics will govern approach.

Future Inspection Requirement: Same as for new steel pile sections.

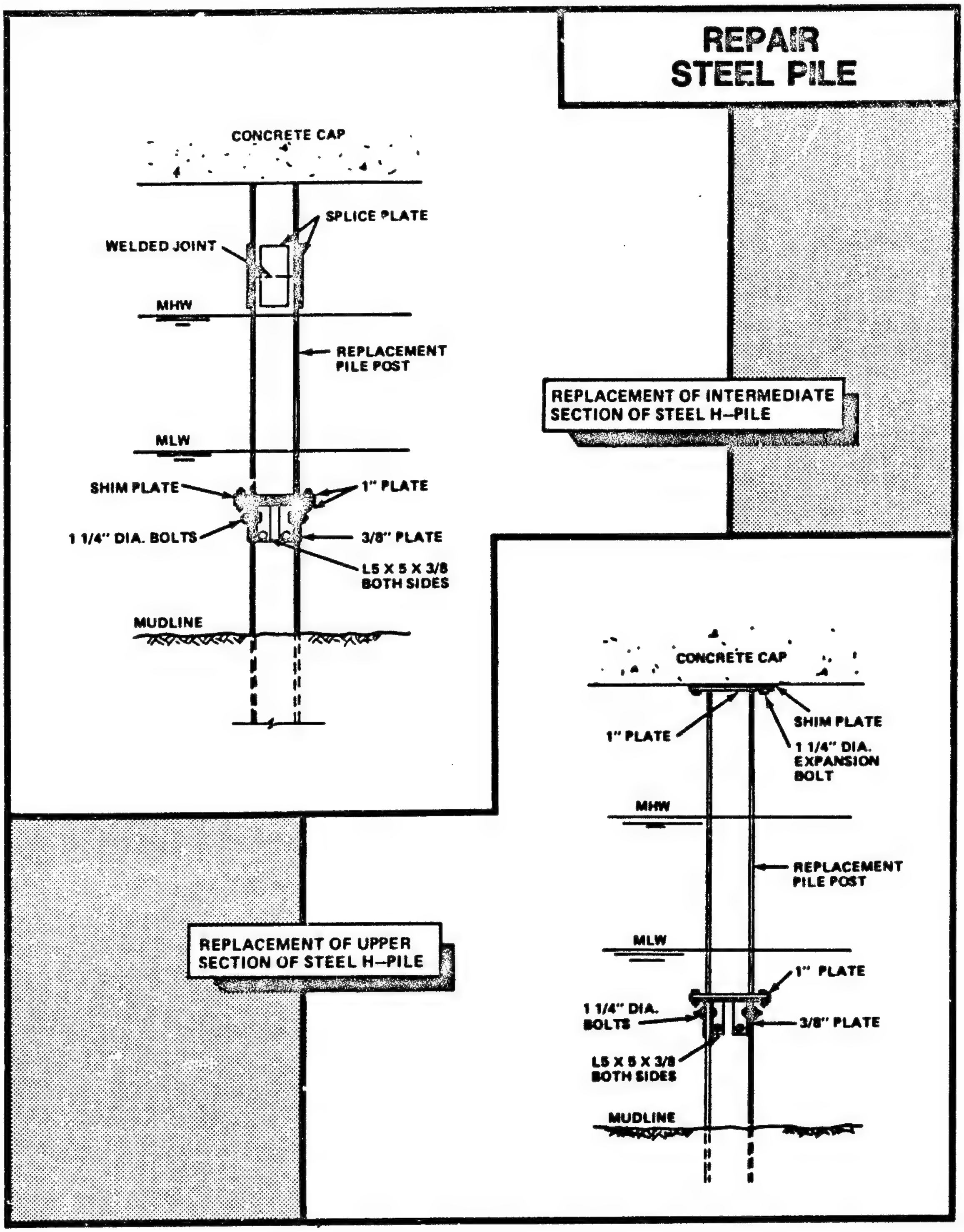


Figure 8-3. Repair by Partial Replacement of Steel Pile.

SR-4: REPAIRING STEEL PILE WITH CONCRETE ENCASEMENT

Problem: Slight to moderate deterioration (less than 35 percent) of the cross-sectional area has occurred; or protection against corrosion and abrasion is required.

Description of Repairs: Clean the steel pile of all marine growth and loose rust using a high pressure waterblaster. Two methods may be used to provide the concrete encasement, flexible and rigid form. In addition, steel angles may be used with the rigid form, to regain some of the reinforcement in the steel pile where greater levels of deterioration have occurred (figure 8-4).

After the piles have been thoroughly cleaned, a 6- by 6-inch reinforcing mesh is placed around the pile, using spacers to maintain clearance between the pile, reinforcing, and fabric form. The fabric form should be placed around the pile.

> **For the Flexible Form:** The zipper should be closed, and the form secured to the pile at the top and bottom with mechanical fasteners (figure 8-4).
>
> **For the Fiberboard Form:** The straps are installed and secured every 12 inches. A minimum of 1-1/2-inch spacing is to be maintained between the pile and reinforcing and between the reinforcing and form (figure 8-4).

The annular space between the pile and the form is then filled to overflowing with concrete grout using a tube or hose extending down to the lowest point of the form.

The form is left in place and the base is backfilled to above the concrete.

Application: This method can be used as a repair technique or as a protection technique to prevent further rusting or abrasion. The method will not restore bearing capacity lost by the deterioration of the steel cross section. Partial restoration of compressive strength may be gained by the use of steel angles with the concrete encasement. This is not a generally accepted practice, however, so care must be exercised to ensure that the connections are made to sound metal. Many times posting the existing pile with a new H pile section may be more cost effective. Economics would normally govern the decision.

Future Inspection Requirement: Increased inspections may be required to detect signs of potential failure of the repair.

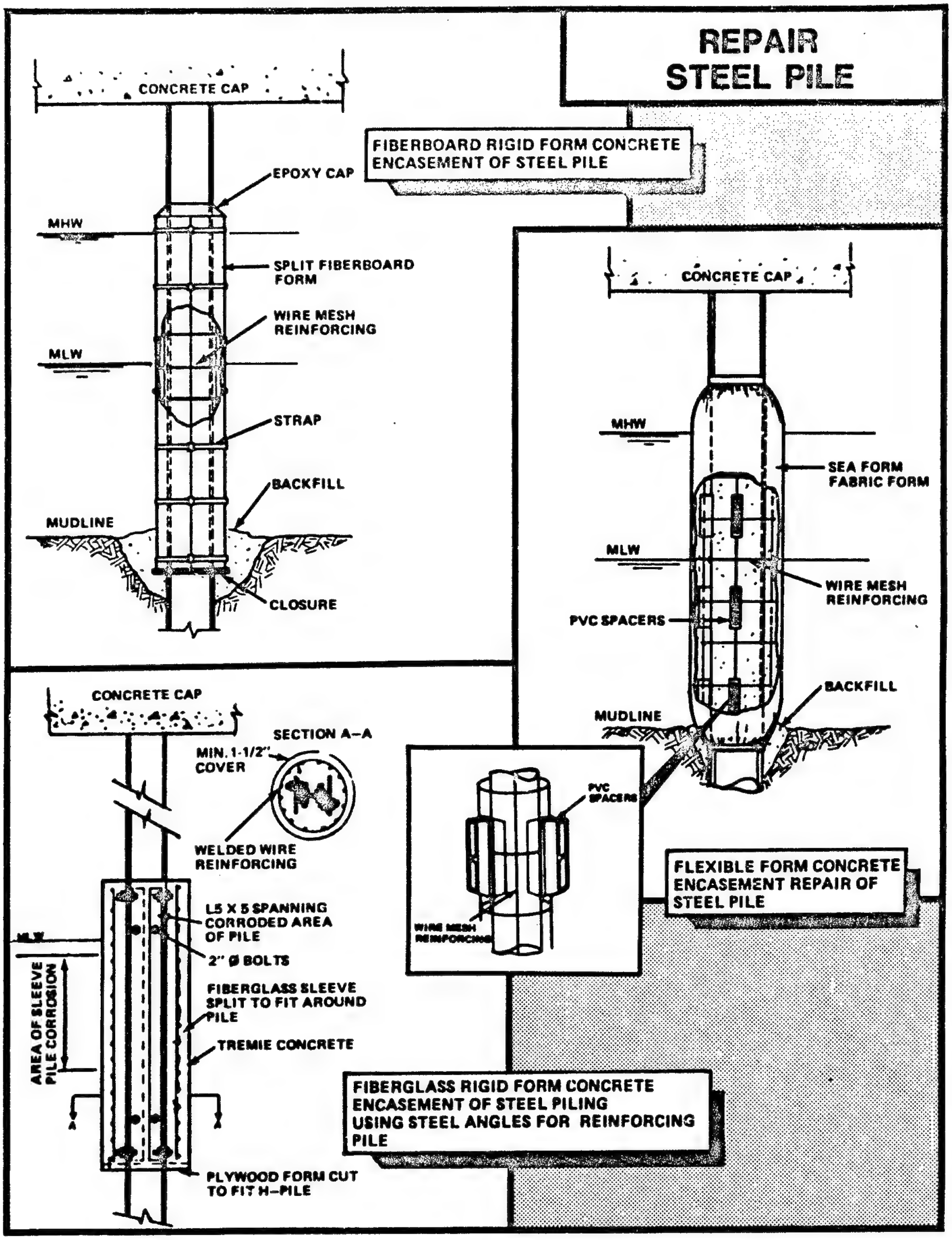


Figure 8-4. Repairing Steel Pile Using Concrete Encasement.

SR-5: COMPLETE REPLACEMENT OF STEEL PILE

Problem: Moderate to heavy deterioration (greater than 35 percent) of the cross-sectional area, or damage, has occurred to a steel H-pile.

Description of Repairs:

Using Existing Pile Cap: Cut an opening in the concrete deck adjacent to the damaged pile. Drive the new steel pile and cut to fit under the existing pile cap. Pull the pile laterally into place (figure 8-5). Shim between the pile and pile cap and secure the pile to the pile cap using 1-1/4-inch expansion bolts.

With New Pile Cap: Cut an opening in the concrete deck between existing pile locations. Drive the new steel pile through the hole cut in the deck and cut off below the top of the concrete deck (figure 8-5). Weld horizontal reinforcing bars to the top of the steel replacement pile or provide suitable reinforcing steel transitions with concrete piles, to ensure load transfer. Form the pile capital under the deck and around the new pile, and fill the form and deck space with concrete. Ensure that new and existing piles are electrically isolated, otherwise accelerated corrosion may be experienced with the new piles.

Application: This method restores the structural strength lost with the deteriorated pile. The same corrosion can occur, however, with the new pile. Concrete encasement or cathodic protection may be used to extend life expectancy. Economics will govern approach.

Future Inspection Requirement: Same as for new steel or concrete pile sections.

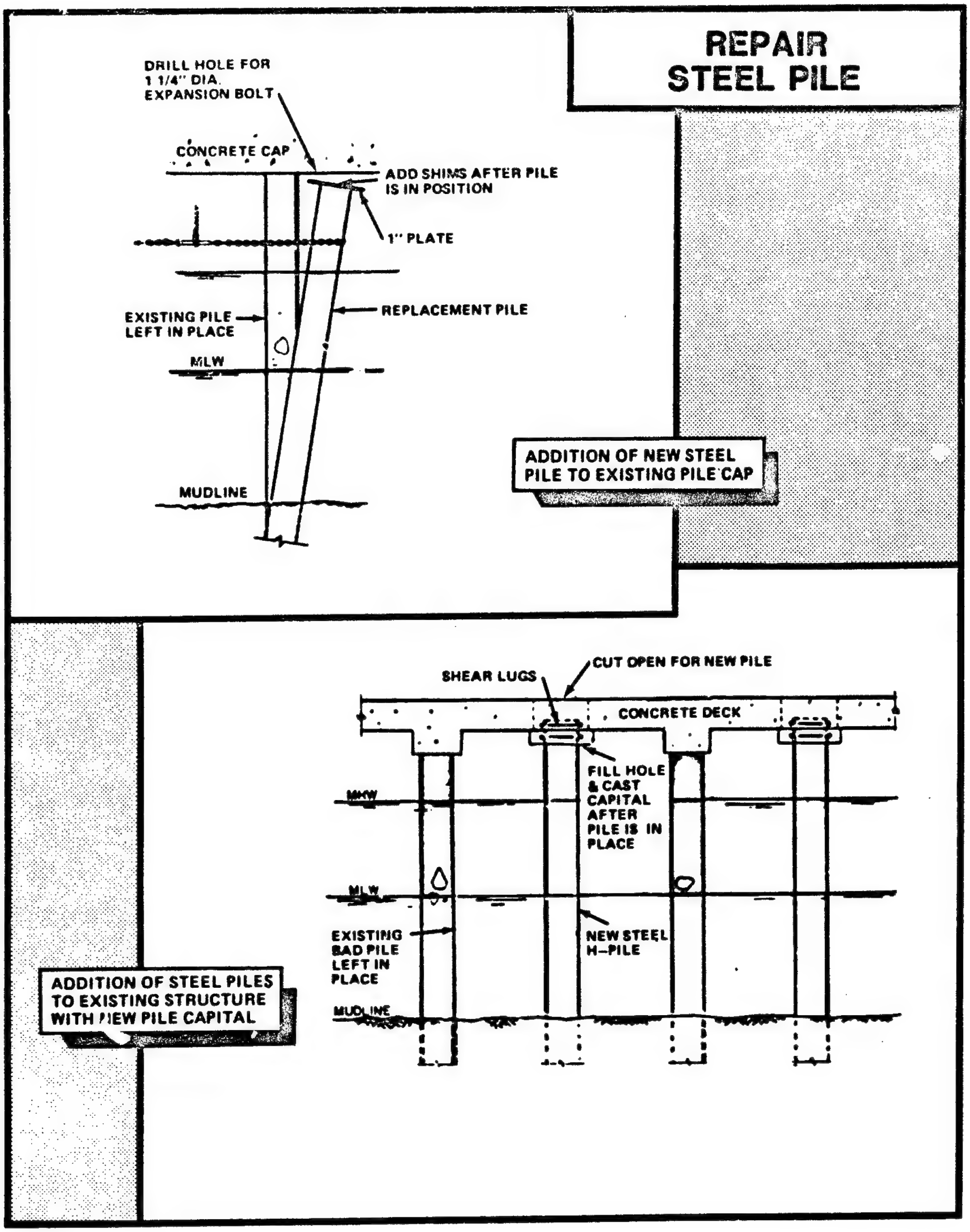


Figure 8-5. Replacement of Damaged or Deteriorated Steel Piles.

SR-6: COATING/CATHODIC PROTECTION OF STEEL SHEET PILE WALL

Problem: A new steel sheet pile wall has been installed or an existing wall has experienced slight surface deterioration. Protection against further corrosion is required.

Description of Repairs: Three procedures may be followed in providing protection for steel sheet piling:

Paint Coating: Clean steel of all marine growth and loose rust using abrasive blasting equipment or water jetting equipment. Apply the paint coating following MIL-P-24441 guidelines.

Epoxy-Polyamide Coating: Clean steel above water with abrasive blasting equipment and underwater with water jet cleaning equipment. Mix epoxy and polyamide coating ingredients in ambient temperature of about 70°F. Apply epoxy coating by smearing by hand over steel surface to a thickness of 1/8 inch to 1/4 inch (figure 8-6).

Cathodic Protection: For sacrificial anode system, place anodes below low water on steel by welding or bolting. Size, type and spacing of anodes must be determined to suit structure and environment. Positive electrical connection between adjacent piling must be made (figure 8-6). For impressed current systems, place anodes off the face of the sheet pile wall.

Application: If water temperature is less than 60°F, proper bonding of the epoxy may not occur. Successful application requires a neutral or positive charge on the structure; negatively charged steel repels the negatively charged epoxy coating. Underwater application may be difficult. Prior to ordering the coating, a sample area of the surface to be coated should be tested under conditions identical to those in which the project will be carried out to be sure that the coating will adhere properly.

The cathodic protection system requires careful design and installation. Improper design or installation could, in fact, cause an increase in the corrosion rate. In addition, the system is not effective for mitigating corrosion above mean low water.

Future Inspection Requirement: Increased inspection may be required, particularly in areas where ice may be present, in order to detect signs of abrasion of the mastic or removal of the anodes, and renewed corrosion of the sheet piling.

PROTECTION STEEL WALL

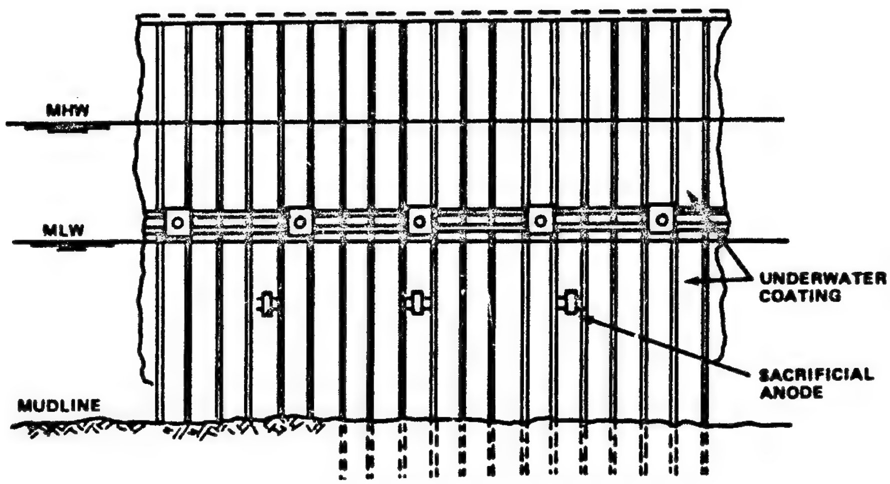


Figure 8-6. Coating/Cathodic Protection of Steel Sheet Pile Wall.

SR-7: PATCHING OF STEEL SHEET PILE WALL

Problem: Small to medium holes exist in steel sheet pile wall. General condition of sheet piling is otherwise sound with minimum signs of corrosion.

Description of Repairs: Clean around area to be patched. For larger holes using steel plate patches, clean sheet piling from 18 inches below holes to above MLW.

Epoxy Patch: Weld wire mesh or bolt fabric mesh over holes and cover with epoxy mastic smeared on by hand (figure 8-7). Good for a limited number of small holes.

Steel Plate Patch: Determine size of patch plate needed. Cut plate to size and bend plate to fit over sheet pile interlocks. Weld plate in place at top, above low water. Cut holes for Tee bolts in sheet piling behind holes in plate; place and tighten Tee bolts (figure 8-7). Alternative is to weld plate all around. More appropriate for larger hole or several small holes.

Patch and Pressure Grouting: Where several small holes make pure patching cost prohibitive, a combination of patching and grouting may be a better solution. In this approach, cover the larger holes with epoxy or steel plate patches, then pressure grout the area behind the wall (figure 8-7).

Application: This approach will not prevent further corrosion and its success is highly dependent on the surrounding areas of sheet piling being relatively sound and free from rust. Continued deterioration of a weak structure, particularly near tie-backs, could lead to rapid failure and poor use of repair funds. Economics should govern final selection of the repairs method.

Future Inspection Requirement: Increased inspection will be required at the patch areas to ensure that welds and bolted connections continued to hold.

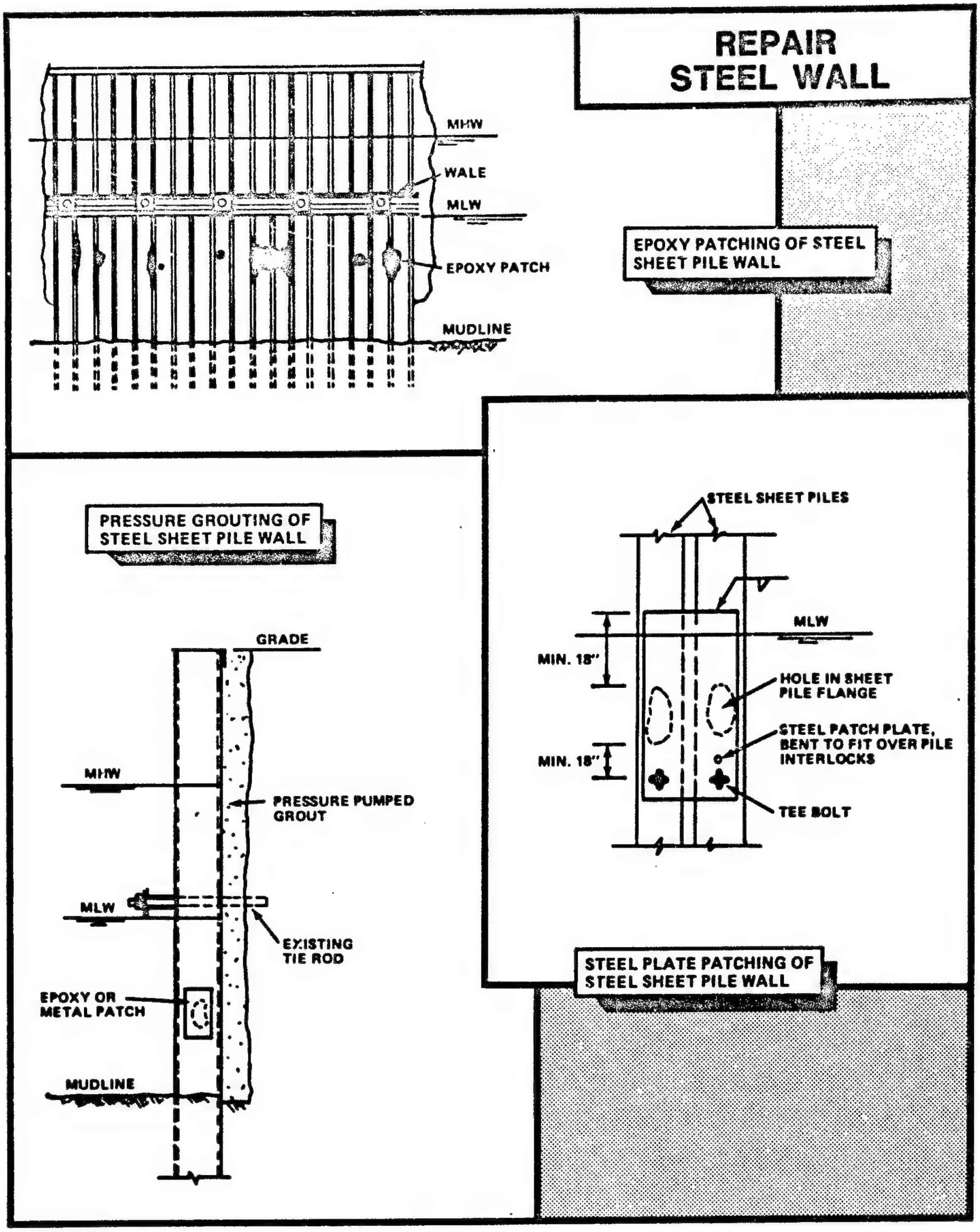


Figure 8-7. Repairs to Steel Sheet Pile Walls Using Various Patching Techniques.

SR-8: REINFORCING TIE-BACK SYSTEMS FOR STEEL SHEET PILE WALL

Problem: Light to moderate movement of the top of the steel sheet pile wall has occurred due to tie-back failure or excessive loading behind the wall. The area behind the wall is accessible to perform repairs.

Description of Repairs: Install a new wale slightly above the existing wale. Locate the new deadman anchors based upon engineering calculations. Trench for the tie rods between the wall and the deadman anchors. Place the tie rods through the wale and sheet piles and secure in place to the deadman anchors (figure 8-8). Ensure sufficient clearance is allowed through the sheet piles to electrically isolate the tie rods from the piling. Install zinc or magnesium packaged anodes to prevent future corrosion of the rods.

Replacement of an existing tie-back system may involve the replacement of any or all of the existing components, depending on the amount of deterioration that has taken place.

Sheet pile wall movement can also sometimes be arrested by changing the soil loading acting on the wall. For example, stone riprap dumped against the exterior toe of the wall will add resistance to the movement of the toe. Alternatively, or in addition, backfill can be removed from behind the wall and replaced with lightweight granular fill. This type of fill has the advantage of being free-draining, which reduces the hydrostatic pressure behind the wall and allows the water level on both sides to balance.

Application: Reinforcing or replacing the tie-back system may be restricted to correction of slight to moderate wall deflection. Excessive deflection may require wall replacement or major restoration.

Future Inspection Requirement: Careful attention must be given to inspecting the wall for further signs of continued deflection or steel member failure.

REPAIR STEEL WALL

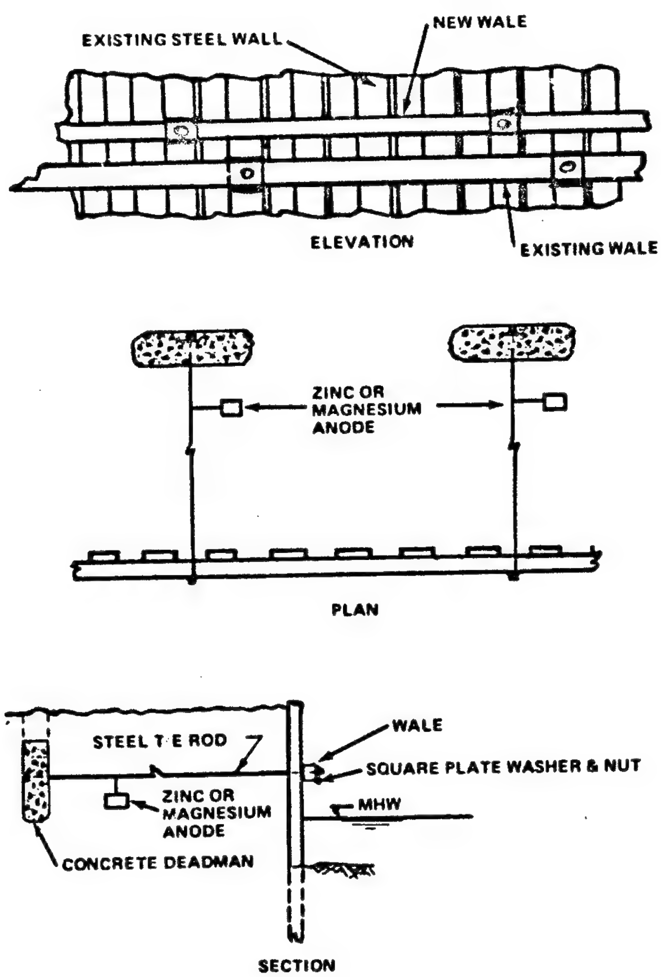


Figure 8-8. Installing or Replacing Tie-Back Systems for Steel Sheet Pile Wall.

SR-9: REPLACEMENT OF EXISTING STEEL SHEET PILE WALL

Problem: Serious deterioration of the steel sheet pile structure has occurred precluding the use of patches for repair.

Description of Repairs: Two methods are available for replacing deteriorated steel sheet piling:

Timber Sheet Piling: Remove decking (if required) behind existing steel sheet pile wall to provide enough space to excavate and drive timber piling. Excavate to expose tie rods (usually these are above mean low water). Place new timber wales to act as template for driving timber sheeting. Drive timber sheeting (figure 8-9). Backfill - may not be possible between steel sheeting and timber sheeting below wales. Replace decking (as applicable).

Steel Sheet Piling: Drive new steel sheet piling in front of existing sheet piling. Drill hole for tie rod and pipe casing through both walls into stiff clay, out of active zone behind old wall. Pressure grout inside casing forming bulb in clay at end of casing (figure 8-9). Fill space between old and new sheet piling with concrete. If stiff clay is not available, deadmen may need to be added to secure the tie rods. Ensure electrical isolation is maintained between the existing and new sheet piling, especially through tie-rods.

Application: Either solution should stop the loss of backfill through the existing steel sheet piling wall.

The timber sheet piling should be less expensive than the new steel sheet piling wall. However, the timber piling will require access behind the existing wall, and continued corrosion of the existing steel sheet piling can be expected.

The new steel sheet piling can provide a new wall with equal or greater strength; and construction can be accomplished without excavating behind the existing wall. This approach does, however, require grouted tie rods to be secured in existing soil. If stiff clay or other suitable soil is not available, this method may not be appropriate unless deadmen are added.

Future Inspection Requirement: Normal inspection requirements should suffice for the new steel sheet pile wall. If the timber piling approach is used, more extensive annual inspections may be required to watch for signs of potential timber piling deterioration and failure behind the existing wall.

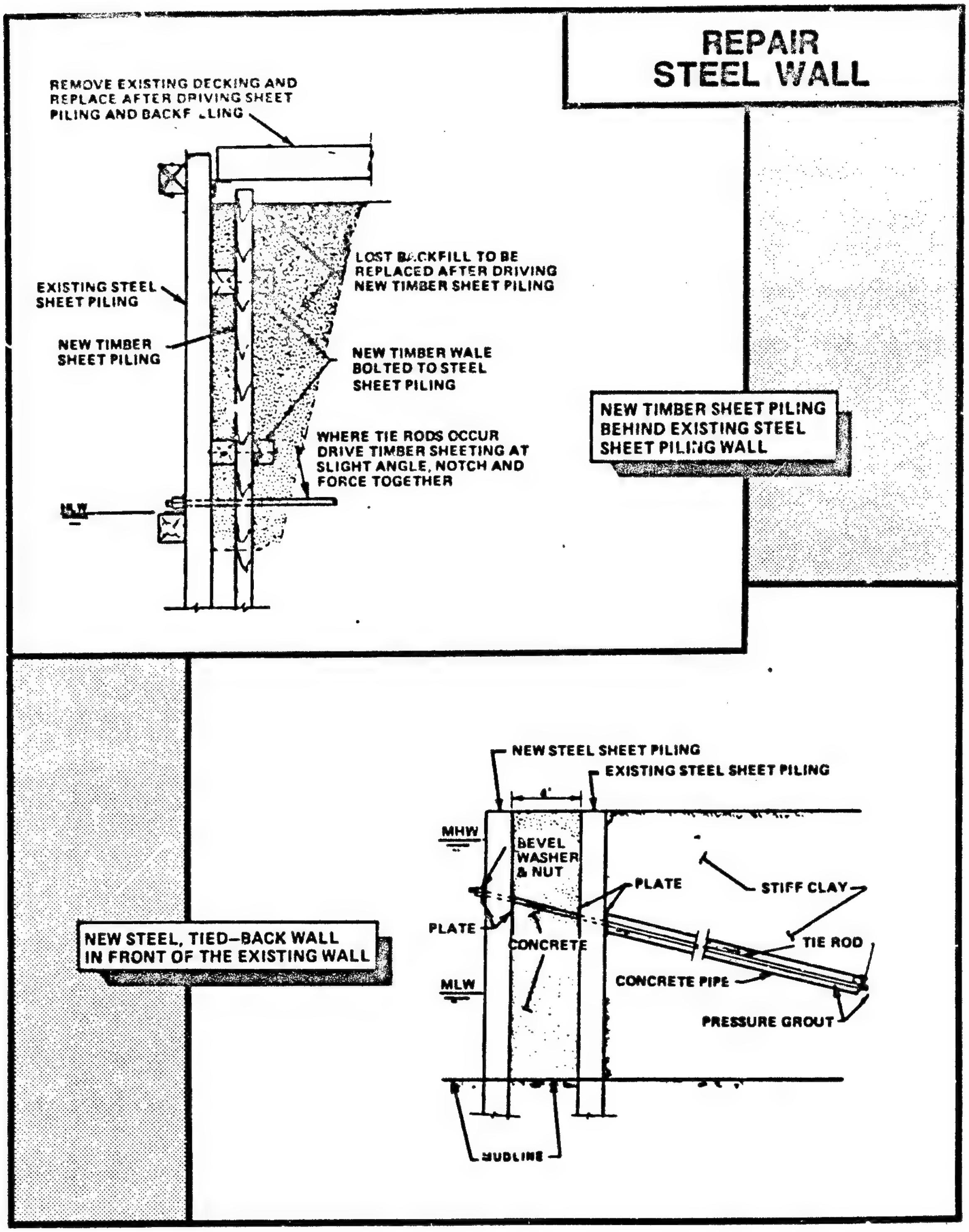


Figure 8-9. Replacement of Existing Steel Sheet Pile Wall with New Steel Sheet Piling or Timber Sheet Pile Wall.

SR-10: INSTALLING A CONCRETE CAP/FACE ON A STEEL SHEET PILE WALL

Problem: Large-scale deterioration of the steel sheet pile structure has occurred precluding the use of patches for repair.

Description of Repairs: Excavate the soil from behind the wall to a level required for the new concrete cap or attachment of form ties for a concrete face. Remove all marine growth and deteriorated steel, and clean surfaces.

For Concrete Cap: Build forms, place reinforcing and pour concrete at MLW. After curing, remove forms and backfill behind wall (figure 8-10).

For Concrete Face: Place and fasten blocking and low wale against existing sheet piling. Drive the timber sheet pile wall about one foot in front of existing sheet piling using wale as guide. Attach outside wales to timber sheeting and place concrete by pumping or tremie. Leave timber sheet piling in place or remove as desired (figure 8-10).

For partial concrete facing of steel sheet pile wall, techniques exist to repair a deteriorated wall from the exterior side without requiring excavating. One method uses timber formwork (figure 8-10), welding steel studs to the steel sheet pile at locations where the metal is sound. The shear lugs help to hold the concrete in place. A temporary steel frame, which supports the timber formwork, is suspended from the top and welded to the exterior of the wall above the waterline. Blocking is used to maintain a 12-inch minimum space, and reinforcing is placed in the center of the space. Concrete is placed by pumping or tremie method. The formwork can be removed within a few days.

Application: Used to restore structural strength at the top of the wall (cap) or prevent further loss of soil through holes in the sheet piling (face). Does not restore bending moment capacity in wall. Provides protection against further deterioration.

Future Inspection Requirements: Careful inspection should be made annually involving the sheet piling areas immediately under the pile cap, in order to ensure that further corrosive damage is not being experienced significantly weakening the support for the concrete cap. Similar procedures need to be followed for partial concrete faces. For complete concrete facing, normal inspection procedures should be followed.

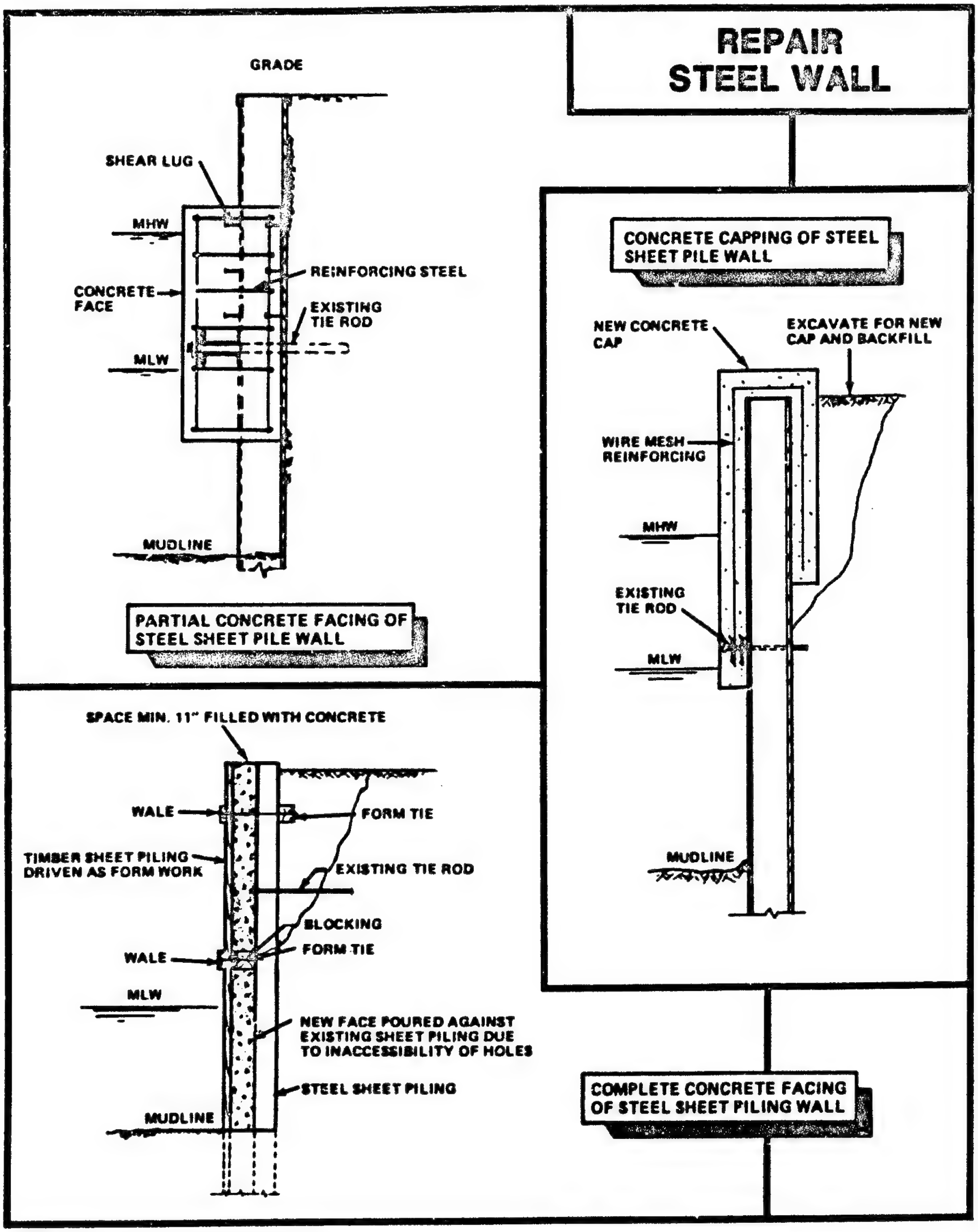


Figure 8-10. Installing a Concrete Cap and/or Face on a Steel Sheet Piling Wall.

SR-11: SCOUR PROTECTION FOR STEEL PILE SUPPORTED WATERFRONT STRUCTURE

Problem: Serious erosion of seabed material has occurred around a marine structure as a result of wave action and/or strong current.

Description of Repairs: Two methods are available for scour protection: riprap placement and steel sheet piling.

Riprap Placement: Replace the lost foundation material. Place riprap by dumping stones randomly into place. If riprap in the form of stones is not available, use bags of synthetic fiber woven water-permeable material filled with concrete. On sandy seabeds, a filter fabric may be required under the riprap or bags to prevent scour through the individual units (figure 8-11). The materials most commonly used are commercially available, synthetic fiber, non-woven fabrics weighing between 8 and 12 oz/yd^2, or woven fabrics weighing between 5 and 7 oz/yd^2.

Steel Sheet Piles: Drive steel sheet piling around structure to protect soil around the bearing piles (figure 8-11). The decision regarding replacement of the lost foundation material under the structure should be based on the strength of the exposed piles.

Application: A careful evaluation should be performed to determine if: (1) any settlement of the structure has occurred due to the scour, or (2) suitable bearing capacity exists within the remaining structural foundation to support the loading. Selection of either scour protection technique should ensure that suitable structural integrity exists prior to commencement of repairs.

Future Inspection Requirement: Normal inspection requirements will generally suffice. If riprap is used, annual underwater inspection will be required to ensure that material is not lost.

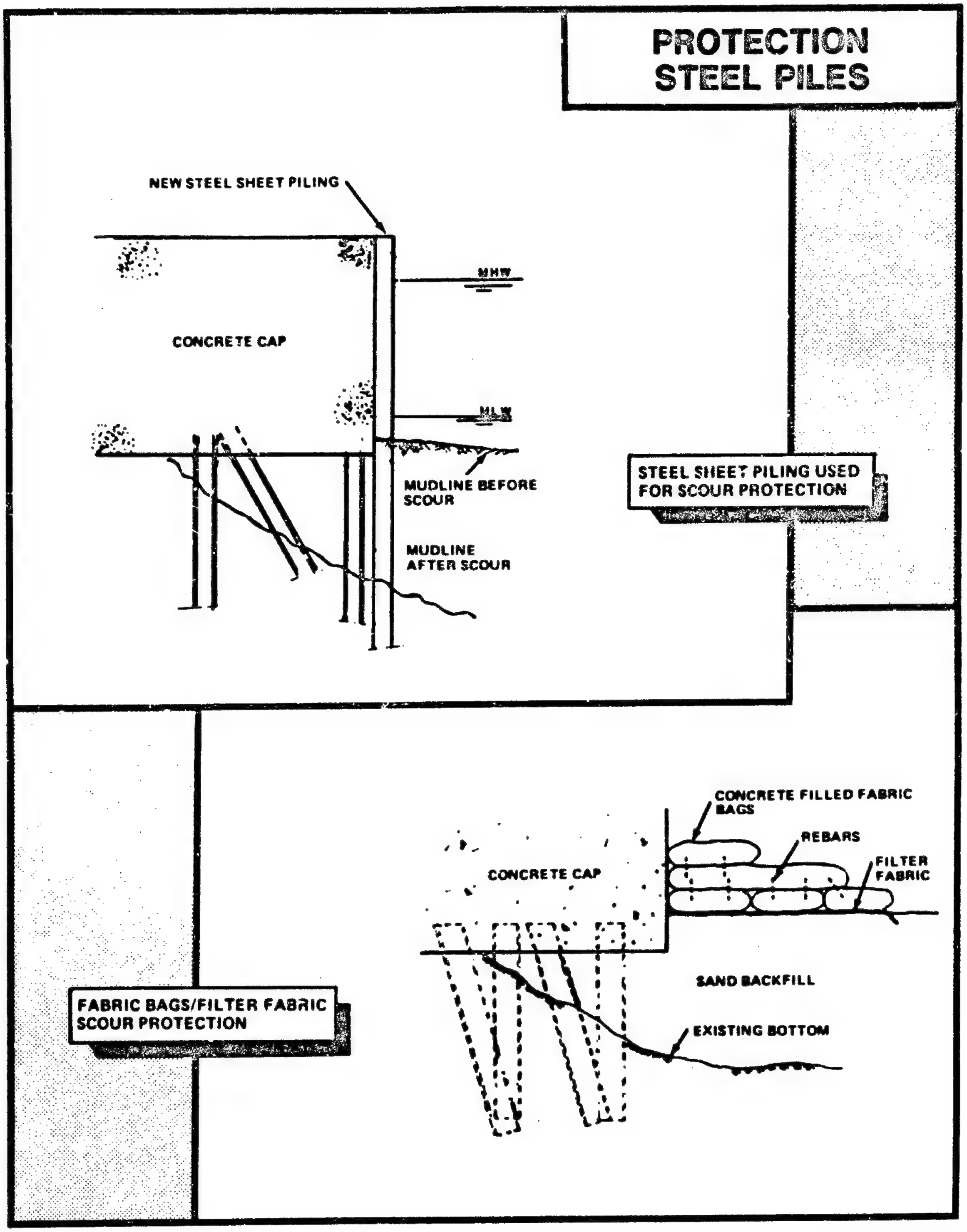


Figure 8-11. Scour Protection For Steel Pile Supported Waterfront Structure.

CHAPTER 9. REPAIR OF SYNTHETIC MATERIALS

9.1 GENERAL. Synthetic materials typically used on waterfront structures include:

- Structural components such as railings and stanchions, resilient fenders, light standards, gratings, and piping.
- Coatings and jackets for piles and piping.
- Buoyancy materials used in buoys, floats and foam-filled and pneumatic fenders. Foam-filled fenders, smiliar to those shown in figure 9-1, are significantly increasing in use in the waterfront environment.

Deterioration of these synthetics results from physical damage, exposure to the environment, aging, and/or a combination of these factors. Physical damage is the most common type of deterioration for railings and stanchions, light standards, gratings, resilient fenders, pile coatings and jackets, and foam filled fenders used in a waterfront environment. Field exposure results in plastics cracking, separating or becoming brittle; foams crumble with age and lose resilience; and elastomeres stretch and deteriorate from the effects of sun and exposure. Aging may be more of a contributing factor in the waterfront environment than most other causes of deterioration.

9.2 PLANNING THE REPAIRS. Accomplishment of repairs to synthetic materials and components will normally be controlled by the position of the components (or material) within the waterfront structure. Components such as railings, stanchions, resilient rubber fenders, light standards, gratings, and piping will normally be repaired by replacement and are within the capability of shop forces. Repairs of coatings or jackets on piling will frequently involve skilled personnel and specialized equipment, thereby necessitating repairs to be accomplished by contract. Repairs to foam-filled fenders may be accomplished either by shops forces or the manufacturer depending upon the extent of damage or deterioration.

Specialized skills and equipment for applying coatings, jackets and patches on piling are covered in chapters 6, 7 and 8.

Special instructions and equipment requirements for repairing foam-filled fenders are specified by the manufacturer. Repair kits for reinforced and unreinforced fender shells are made up of the following:

a. Unreinforced Fender Shell:

- Two-part elastomer and curative compounds
- Two-part primer
- Closed-cell polyethylene foam blocks
- Material data sheets

b. Reinforced Fender Shell: All items in section a. above plus:

- Nylon webbing (lacing)
- Nylon netting for repair of reinforcement
- Elastomer thickener

Other materials needed for the kit such as paper cups, razor blades, stirring sticks, masking tape, sand paper, paint brushes, and putty are items that can be readily acquired.

9.3 REPAIR PROCEDURES. Repair of deck hardware, rubber fenders and piping will be by replacement and will be accomplished in accordance with standard shop industrial practices. Repair of coating, patching or jacketing materials on piling will conform to the repair procedures outlined in chapters 6, 7 or 8.

Field repairs to reinforced and unreinforced shell foam-filled fenders are outlined in synthetic material repair procedures that follow. Severe shell, foam and end fitting damage, caused by over compression, should be repaired at the factory.

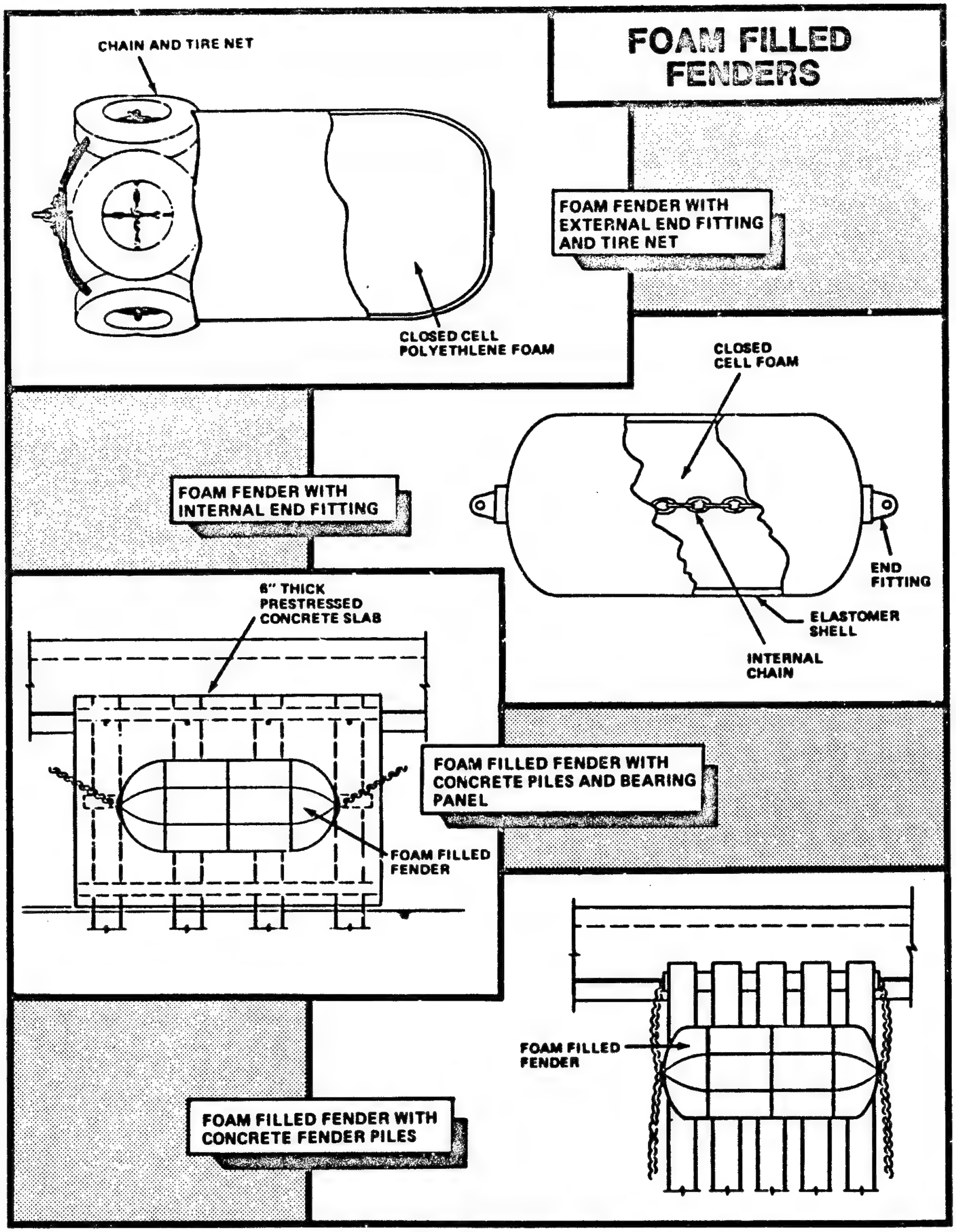


Figure 9-1. Typical Foam-Filled Fenders Used in Waterfront Berthing.

REINFORCED SHELL, FOAM-FILLED FENDER REPAIR

Problem: Minor shell abrasion, shell or foam burns, punctures, cuts or tears have occurred necessitating field repairs to prevent further damage.

Description of Repair: Field repairs can be accomplished using a repair kit purchased from the manufacturer, or by developing an in-house repair capability and material inventory.

Preparing Elastomer Components: Heat the closed cans of elastomer polymer and curative components by either wrapping can several times with heat tape, or place in a pan of lukewarm water (120°F) for approximately one hour, or until completely melted.

CAUTION

Do not boil the water. Fill the pan to a water level several inches below the top of can.

Mix curative thoroughly by slowly rolling the can across a table or ground for several minutes. Do not shake the can. Mix the required amount of components in a can and gently stir for 2-3 minutes. Avoid violent stirring that may cause air bubbles.

NOTE

Usable pot life of the mixed components is approximately 10-15 minutes. Mix only as much as can possibly be used in that time.

Place the entire content of the mixed components into the paper cups and mix thoroughly.

Tears and Cracks:

(1) Position the damaged fender so that the area to be repaired is easily accessible.

(2) Buff from 6-8 inches around the perimeter of the crack and within the crack itself, with sidegrinder or sandpaper.

(3) Drill a 1-inch diameter hole at each end of the crack. This should relieve the stress concentration and prevent further propagation.

(4) Drill 1/2-inch diameter holes along both sides and parallel to the crack. Holes should be drilled 2-1/2 inches away from the crack and should be drilled 2-1/2 inches between centers. See figure 9-2.

(5) Thread the nylon webbing through a 1/2-inch diameter hole at one end of the crack. Tie a knot large enough not to slip through the hole. The knot should be on the underside of the shell.

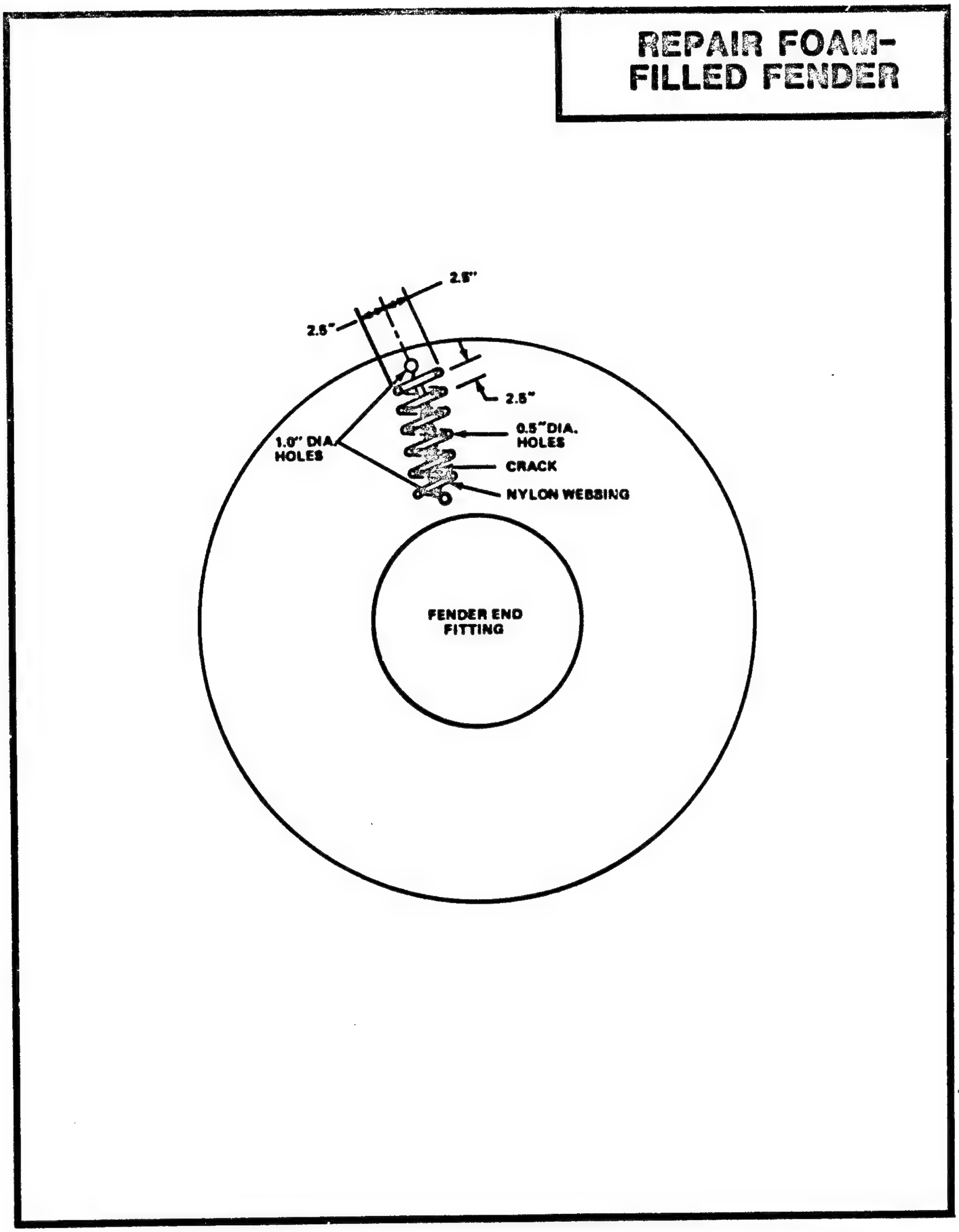


Figure 9-2. Repair of Tear in Reinforced Foam-Filled Fender Shell.

REINFORCED SHELL, FOAM-FILLED FENDER REPAIR (Continued)

(6) Start lacing webbing through the holes. Try not to twist the webbing; webbing should lay flat. Brazing or welding rod is a good tool for threading the webbing through the holes.

(7) Lace webbing through all holes, tie a large loop in the running end and hook it to a come-along or chain jack. Pull the webbing tight using the come-along or chain jack.

(8) Work out all slack in the webbing using a pry bar. Repeat operation until all the slack is drawn out and the crack is closed as much as possible.

CAUTION

Webbing is rated at about 2500 pounds. Try not to pull the webbing beyond that limit.

(9) Clean the area with any available solvent, while the come-along is still attached. Mask-off the buffed and cleaned area.

(10) Mix primer in accordance with the directions and apply to the damaged area. Apply the primer inside as well as around the tear or crack. Allow the primer to dry for 30 minutes, or until tacky.

(11) Cut out several patches of netting slightly smaller than the masked off area and set aside (omit where reinforcing is not required).

(12) Spread elastomer mixture over the entire repair area.

(13) Work a piece of pre-cut netting into the fresh mixture.

(14) Apply a second coat of elastomer mixture and a second layer of netting while the previous coat is still tacky.

(15) Allow the second coat to cure for 30 minutes and release the come-along and trim off the end of the nylon webbing.

NOTE

The webbing may slip back a little, but the elastomer mixture will keep the slippage from being excessive.

(16) Continue applying the mixture until the desired thickness is obtained.

(17) Apply a final coat of the mixture to smooth out the final surface.

REINFORCED SHELL, FOAM FILLED-FENDER REPAIR (Continued)

Burns and Skin Removal:

(1) Position the damaged fender so that the area to be repaired is easily accessible.

(2) Cut the damaged area into a smooth circular contoured shape. see figure 9-3.

(3) Drill 1/2-inch diameter holes, 2-1/2 inches away from the edge of the undamaged skin and 2-1/2 inches between centers around the perimeter (figure 9-3).

(4) Cut a patch of polyurethane similar in shape to the damaged area. Cut the patch so that it overlaps onto the undamaged shell by approximately one inch all around.

(5) Lay patch over the damaged area and mark holes on the patch so that they match up with and are parallel to the holes on the undamaged shell. Marks should be placed 2-1/2 inches away from the edge of the patch.

(6) Drill 1/2-inch diameter holes in the patch where marked.

(7) Sand 6-8 inches around the perimeter of the undamaged shell.

(8) Lace the nylon webbing, mix and apply primer, and mix elastomer compounds.

(9) Spread the mixture over the entire work area.

(10) Continue applying the mixture until the desired thickness is obtained.

(11) Apply a final coat of the mixture to smooth out the final surface.

Punctures and Gouges:

(1) Position the damaged fender so that the area to be repaired is easily accessible.

(2) Sand and clean around the perimeter and inside the puncture or hole. Use a solvent to clean the area.

(3) Mix and apply primer, and mix elastomer mixture.

Foam Repair (If Applicable):

(1) Position the fender so that the area to be repaired is easily accessible.

REINFORCED SHELL, FOAM-FILLED FENDER REPAIR (Continued)

(2) Cut away the damaged foam forming a rectangular cavity. Use a knife or razor blade to cut out damaged foam.

(3) Cut a block of foam approximately the same size as the rectangular cavity.

(4) Clean the inside of the cavity of foam and elastomer debris.

(5) Mix the elastomer mixture.

(6) Glue the foam block into the cavity using the elastomer mixture.

(7) Repair the shell of the fender by the appropriate method previously described.

Application: The shelf life of the unmixed two part elastomer compound is limited to 6-8 months. Therefore, it is advantageous to purchase the elastomer when the need arises.

In the field, fender repair will involve working with chemicals, so general safety precautions should be observed as follows:

- Avoid elastomer contact with skin and eyes.
- Wear gloves when working with materials.
- Store in temperatures of 65 to 90°F.
- Treat spills with water, alcohol or a mixture of saw dust and dilute ammonia.

Future Inspection Requirements: Increased inspection may be required to ensure that the seam or patch does not rupture.

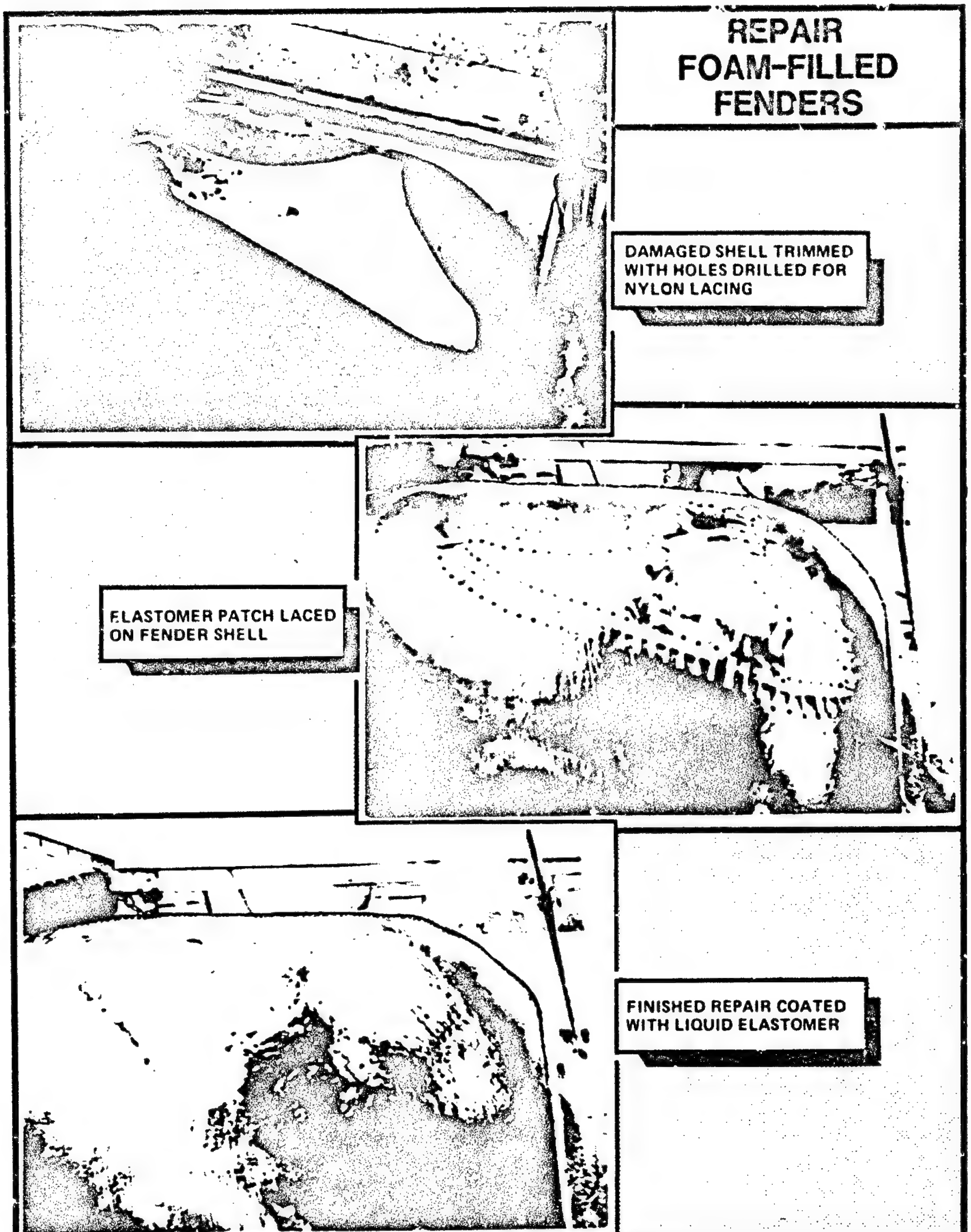


Figure 9-3. Repair of Reinforced Foam-Filled Fender Shell.

UNREINFORCED SHELL, FOAM-FILLED FENDER REPAIR

Problem: Minor shell abrasion, shell or foam burns, punctures, cuts or tears have occurred necessitating field repairs c prevent further damage.

Description of Repairs: Field repairs can be accomplished using a repair kit purchased from the manufacturer, or by developing an in-house repair capability and material inventory.

Preparing Elastomer Components: Heat the closed cans of elastomer polymer and curative components by either wrapping can several times with heat tape, or place in a pan of lukewarm water (120°F) for approximately one hour, or until completely melted.

CAUTION

Do not boil the water. Fill the pan to a water level several inches below the top of can.

Mix curative thoroughly by slowly rolling the can across a table or ground for several minutes. Do not shake the can. Mix the required amount of components in a can and gently stir for 2-3 minutes. Avoid violent stirring that may cause air bubbles.

NOTE

Usable pot life of the mixed components is approximately 10-15 minutes. Mix only as much as can possibly be used in that time.

Place the entire content of the mixed components into the paper cups and mix thoroughly.

Tears and Cracks:

(1) Position the damaged fender so that the area to be repaired is easily accessible.

(2) Using a sidegrinder, grind the edges and inside of the damaged area. Smooth all jagged edges and round off the ends of the tear to relieve stress concentration. See figure 9-4.

(3) Clean off the damaged area.

(4) Force uplift of skin back to its normal position with blocks of wood. Place wood across the uplift and hold down with metal strap (figure 9-5).

(5) Construct a 1-inch high berm with commercial putty around the perimeter of the damaged area (figure 9-5).

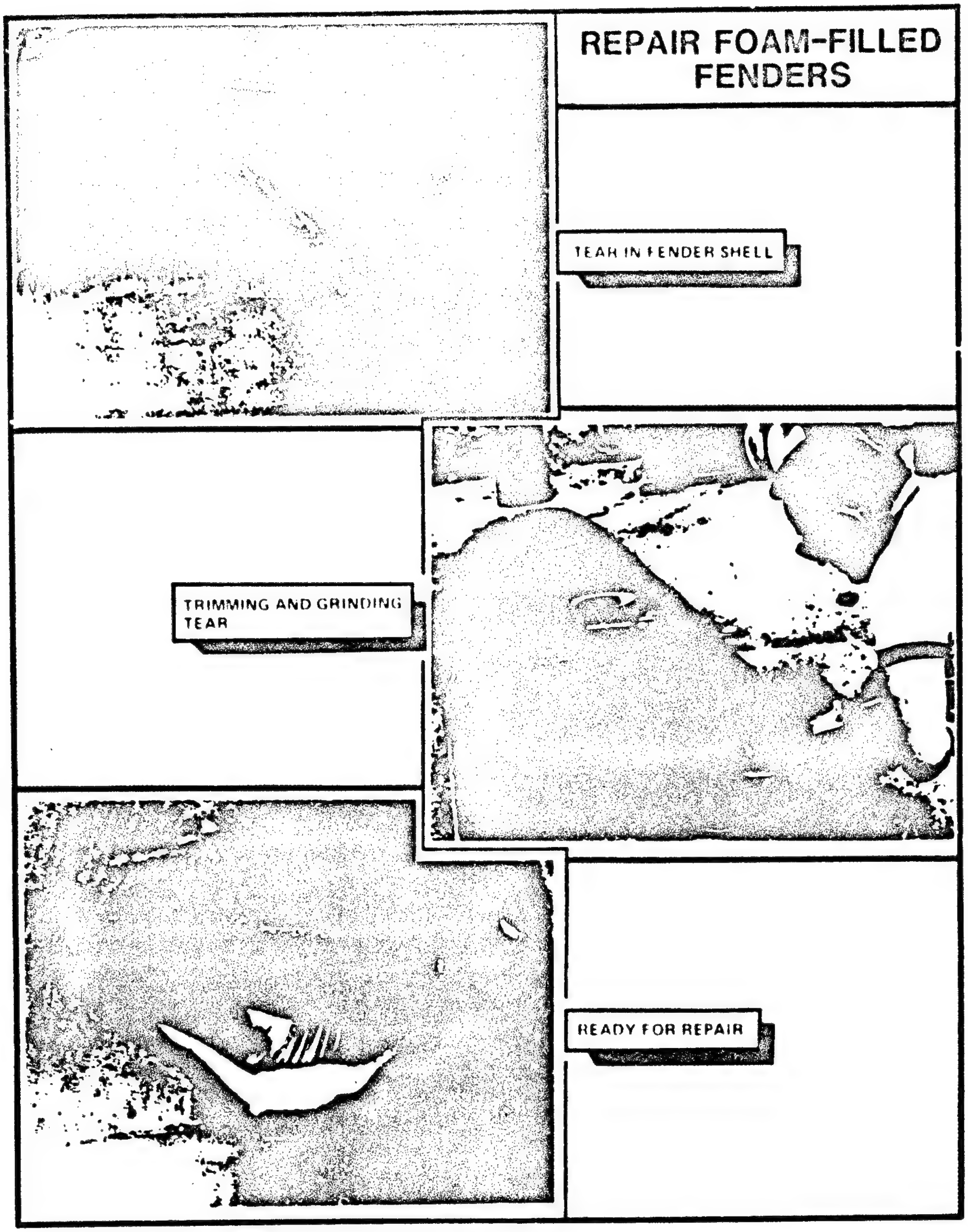


Figure 9-4. Preparing Tear in Unreinforced Foam-Filled Fender Shell for Repair.

(6) Mix and apply the primer.

(7) Mix the elastomer compounds.

(8) Pour mixture into the damaged area until it reaches the top of the berm (figure 9-5).

(9) Let the elastomer cure.

(10) Cut away the excess elastomer until flush with the original fender shell.

(11) Grind or sand the repaired area until smooth.

(12) Apply a final coat of the mixture to smooth out the final surface.

Foam Repair (If Applicable):

(1) Position the damaged fender so that the area to be repaired is easily accessible.

(2) Cut away the damaged foam forming a rectangular cavity. Use a knife or razor blade to cut out damaged foam.

(3) Cut a block of foam approximately the same size as the rectangular cavity.

(4) Clean the inside of the cavity of foam and elastomer debris.

(5) Mix the elastomer mixture.

(6) Glue the foam block into the cavity using the elastomer mixture.

(7) Repair the shell of the fender by the appropriate method previously described.

Application: The shelf life of the unmixed two part elastomer compound is limited to 6-8 months. Therefore, it is advantageous to purchase the elastomer when the need arises.

In the field, fender repair will involve working with chemicals, so general safety precautions should be observed as follows:

(1) Avoid elastomer contact with skin and eyes.

(2) Wear gloves when working with materials.

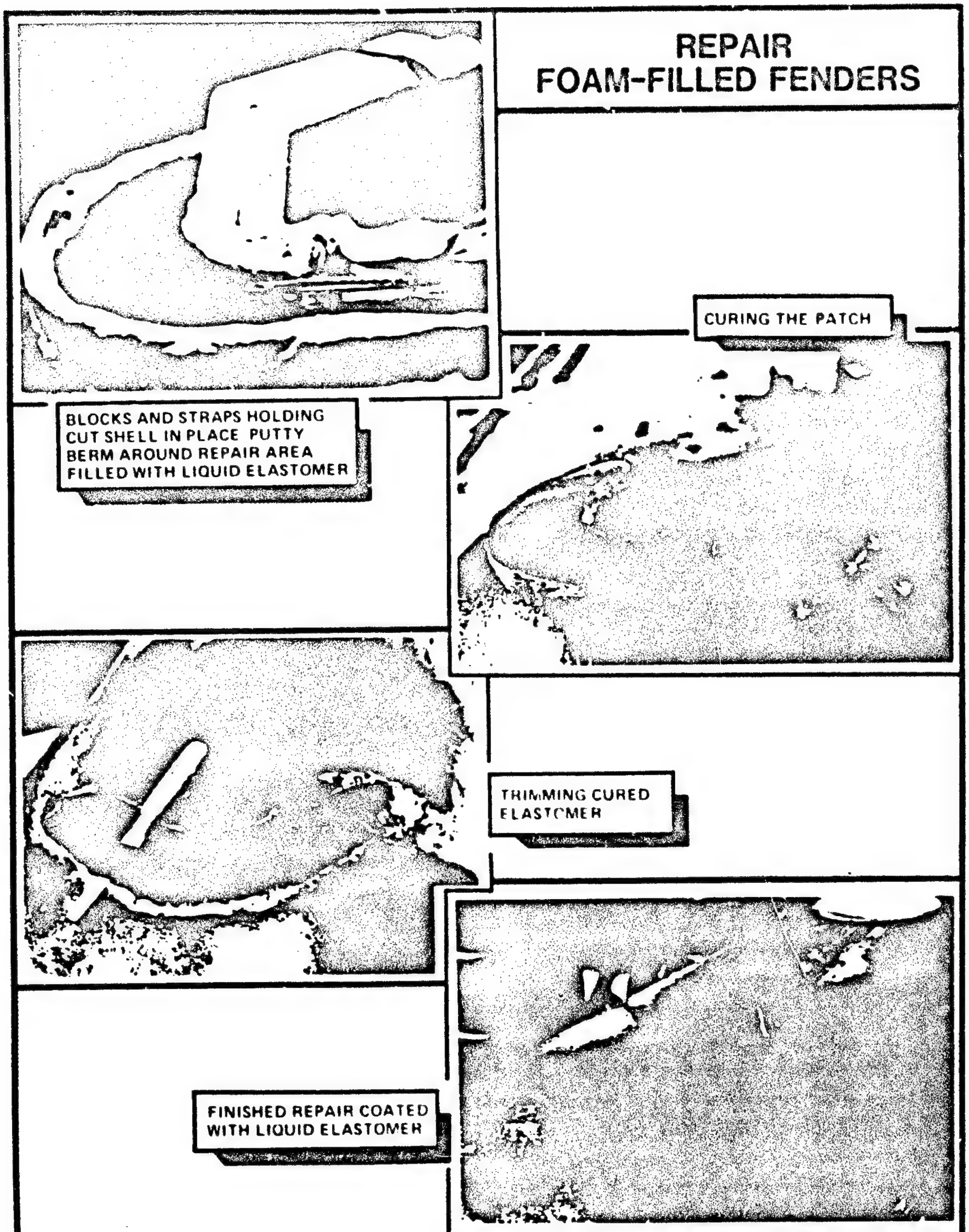


Figure 9-5. Repair of Unreinforced Foam-Filled Fender Shell.

UNREINFORCED SHELL, FOAM-FILLED FENDER REPAIR (Continued)

(3) Store in temperatures of 65 to 90°F.

(4) Treat spills with water, alcohol or a mixturr of sawdust and dilute ammonia.

Future Inspection Requirements: Increased inspection may be required to ensure that the patch does not rupture.

CHAPTER 10. REPAIR OF STONE MASONRY, RUBBLE-MOUND, AND EARTH-FILLED STRUCTURES

10.1 STONE MASONRY STRUCTURES. The quarried and trimmed building stone in these structures seldom develop maintenance problems except at the joints. Other, less frequent types of failure and damage have included:

- Settlement due to loading, soil subsidence, or failure of the foundation.
- Displacement of stones by wave action.
- Scouring and undercutting by sea action.

The only preventive measures to be taken involve keeping weep holes cleared for drainage, and maintaining periodic level readings to help detect settlement. If settlement or adjacent soil subsidence is detected, an investigation to determine the cause is necessary.

10.2 RUBBLE-MOUND STRUCTURES. A rubble-mound is an artificial embankment or ridge composed of sand, gravel, and cobbles, as shown in figure 10-1, constructed on the oceanic floor by dumping the material from scows and barges. The dumping operation continues until the mound emerges a certain distance above the mean seawater level. Wave action on the mound gives the sides a natural stable slope. Since wave action decreases as the water depth increases, the natural side slopes of the mound are steeper in deeper water; this is a function of top elevation of the mound, bottom configuration, and tidal range. Rubble-mound structures are used extensively, because they are adaptable to most any depth of water in the vicinity of harbors and can be repaired readily. If the bottom is not rocky, rubble can protect against scouring that otherwise might occur at the foot of the mound.

10.3 EARTH-FILLED STRUCTURES. Earthworks, consisting of soil materials generally enclosed within a protective covering of coarse stone riprap, timber, steel, or concrete are used for waterfront structures such as dikes, levees, breakwaters, causeways, groins, and seawalls. Soil is used as backfill for quaywalls, caissons, other cellular structures, and as the basic bulk material for closed/mole piers. The common causes of damage are erosion by water and settlement due to undermining, washouts, and the like.

10.4 PLANNING THE REPAIRS. Accomplishment of repairs to stone masonry, rubble-mound or earth filled structures must consider:

- The scope of damage and/or deterioration.
- Rate of deterioration and overall age of the structure.
- Mission requirement for the structure.
- Operational constraints placed upon the facility because of the deterioration.

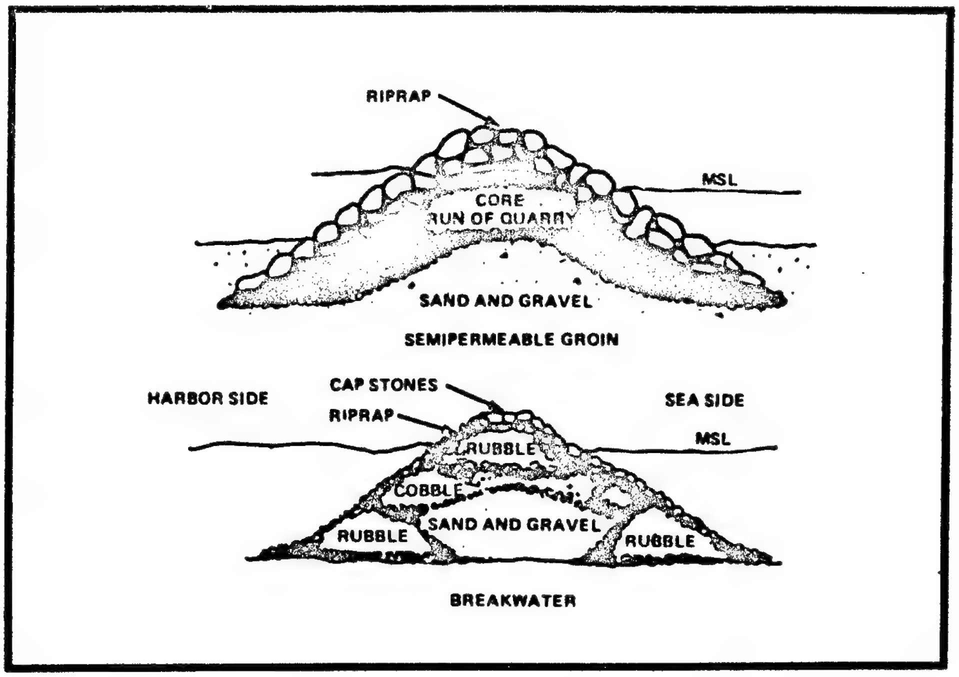


Figure 10-1. Typical Rubble-Mound Structures.

- Changes to environmental conditions, such as currents, caused by other coastal or harbor changes.
- Alternatives for repairing the structure.

In many cases, usage requirements for the facility may have changed. Stone masonry bulkheads and earth-filled vertical bulkhead structures, as an example, may no longer be required for other than retaining the surrounding shoreline. The solution may involve usage of riprap to shore up the structure or reduce seepage and loss of backfill, rather than performing expensive repairs to the structure.

For rubble-mound structures and other applications involving riprap, special consideration must be given in the planning phase regarding:

- Availability of materials including quarry sites.
- Capabilities to quarry and transport to the coastal site, including the availability of barges, scows, and trucks.
- Method of placement; individual versus dumping, including availability of clamshells, draglines and cranes.
- Restrictions on roads and bridges regarding over-the-road transport of rock.

To make optimum use of local materials, designs should not only have a wide range of stone sizes to choose from, but also an adequate number of classes within each range. Each class available for a specific use should be limited in range. Physical limitations on the size of armor stone that is feasible to use must also be considered. These may be truck or highway capacity or the handling limits of the quarry equipment. The geological structure of the rock quarry may also limit the quantity and size of stone that can be obtained. In general, the maximum size armor stone that can be handled is 30 tons. Specific riprap may typically range between 2 to 4 tons.

Once the scope of repair requirements, including priorities, are established, the method of accomplishment must be determined, whether in-house or by contract.

10.5 REPAIR PROCEDURES. The procedures contained in this chapter describe the general approach involved in most repairs to the following types of structures:

- Stone Masonry Structure Repair
- Rubble-Mound Structure Repair
- Earth-Filled Structure Repair

STONE MASONRY STRUCTURE REPAIR

Problem: Joints leak; settlement has occurred due to loading, soil subsidence, or foundation failure; stones have been displaced by wave action; or scouring or undercutting has been encountered due to sea action (figure 10-2).

Description of Repairs:

a. **Joint Repair:** Defective joints can usually be repaired by tuck-pointing with portland cement mortar. A skilled stone mason is required. Tuck-pointing only the obviously defective joints does not ensure that the untreated joints will not leak; therefore, all joints, vertical and horizontal, in the face of the wall, should be tuck-pointed. This procedure requires removing and replacing all mortar to a depth of at least 5/8 inch throughout every joint. Each joint is raked to a depth not greater than 1 inch, unless the old mortar is so defective that removal to a greater depth is necessary. The old mortar should be sound so that it will serve as the base for the new mortar. All exposed sound mortar must have a clean, square-cut surface. All dust and dirt within the raked joint should be washed out by a jet of water. Wherever old mortar is raked out deeper than 1 inch, the hollow spots must be filled with new mortar first so that a uniform line is created. The cleaned joints are tuck-pointed with the portland cement mortar while the masonry is still damp (not wet) from washing out the raked joints.

In preparing for the repairs, the mortar is mixed at least one hour before use to ensure prehydration, which stabilizes the plasticity and workability of the mortar and minimizes shrinkage after placement. A suitable mortar contains type II portland cement and plasticizer, silica sand, and freshwater. It has a somewhat stiff consistency to enable it to be tightly packed into place. The sand/cement ratio should be about 3 to 1 by volume. Placement is as follows:

- Insert a base layer 3/16 to 1/4 inch thick.
- Insert the second layer when the base is sufficiently set so that no fingerprint can be made.
- Allow the second layer to set for several hours before the joint is finally packed to its full depth and tooled at the face.

After tuck-pointing, the masonry should be maintained in a damp condition for at least 72 hours. Epoxy-based materials may be used as an alternative to portland cement mortar.

b. **Repairing Settlement/Grouting:** Repair may involve pumping grout into underground voids, compacting adjacent soil and adding fill, or excavating and replacing footings or unstable fill. When grouting,

STONE MASONRY STRUCTURE REPAIR (Continued)

holes are drilled at intervals and depths established by the engineering evaluation, and the holes are tested by pumping in water to see if the drilling is adequate and to obtain an indication of volume. The intrusion grout has the consistency of a smooth slurry. An admixture-intrusion aid is used to improve flow and the filling of voids. These types of grouting repairs are usually large-scale projects that require specialized experience and equipment.

c. **Scour Repair:** Scouring and undercutting will call for replacement of fill material and protection from future occurrence by adding riprap at the point of failure. Displaced stones are repaired by replacement.

Application: If joint leakage is localized, grouting may be the most economical approach. If joint leakage is extensive, a combination of joint repair and grouting may be required.

Future Inspection Requirements: Increased inspection frequency may be required to ensure that the repair holds or that the rate of deterioration does not accelerate, and that weep holes are kept clear for drainage.

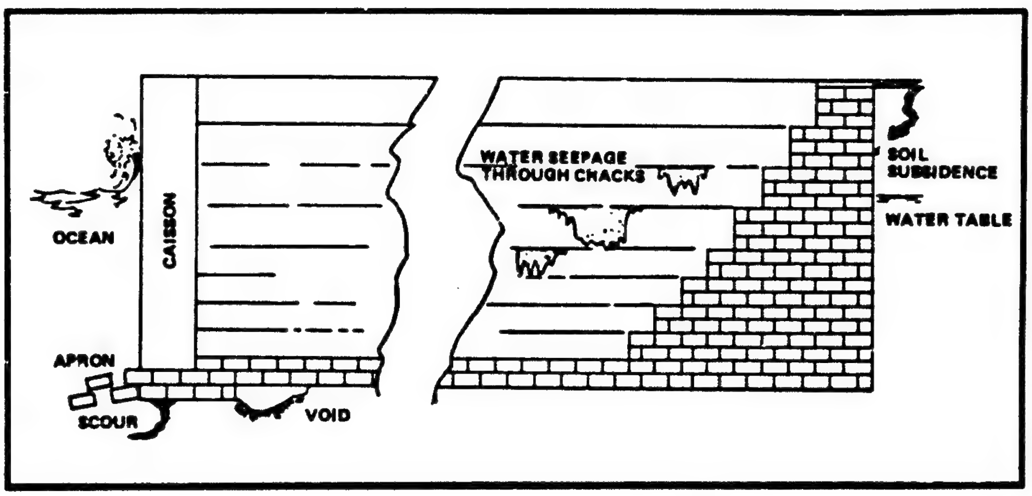


Figure 10-2. Failure and Damage in Stone Masonry Structures.

RUBBLE-MOUND STRUCTURE REPAIR

Problem: The principal types of deterioration in rubble-mound waterfront structures requiring repairs are:

- Sloughing of side slope in the riprap.
- Undercutting of the toe of the structure.
- Slippage of base material as the result of scour by currents.
- Dislodgement of stones by wave action.

Description of Repairs: Repairs consist of replacing and adding to materials in the structure. Maintenance of breakwaters may be expected to be greater than other types of rubble-mound structures. Extreme wave action will dislodge riprap and wash out portions of the mound, which must be replaced.

One of the major causes of damage to breakwaters is the undercutting of the toe. Waves not only exert large impact forces on the armor stone, or face of a vertical structure, they may also impose strong uplift forces on the lower armor stone and toe stone. The armor stone must be placed to a sufficient depth to resist these forces. An additional problem is the turbulence created in these depths, particularly in the case of waves breaking directly on the structure. This can create scour of the sandy bottom and result in undermining the toe stone resulting in general collapse of the armor layer and exposure of the smaller stone of the underlayers. This can be controlled either by carrying the armor and bedding layers to sufficient depth or the toe section can be overbuilt in anticipation of the quarry stone settling into scour holes.

Proper grading of the seaward slope and use of correct classes of stone for the core and capping must be followed in repairs to minimize future maintenance requirements. Even then, material lost must be replaced periodically with materials of the same kind and size as used originally. Adjustments in the seaward slope may be necessary if investigation shows that a change is in order. Change in the type of capping material also may be necessary with the passage of time. Use of concrete tetrapod, tribar, or dolos armor units may improve the structure. If large facing and capping stones are set in a tight pattern, the vertical joints between the stones may need venting, by leveling the corners of individual stones, to permit entrapped air and water to escape. This reduces the lifting action beneath the stones and improves stability.

The replacement of riprap, after replacement of any material washed out of the mound, should retard further scouring. If the scour is produced only by wave action, the problem can be solved by fortifying the toe of the structure with a thick layer of riprap which serves to stabilize the bottom. The rubble must be carefully emplaced so that the smaller stones become wedged in the spaces between the larger stones. Units weighing less than 1 ton should constitute about 15 percent by weight of the additional

RUBBLE-MOUND STRUCTURE REPAIR (Continued)

riprap, and the maximum weight of each of the larger stones should approximate 3 tons. The minimum dimension of any stone should be at least one-third of its maximum dimension.

If the scour is caused by offshore underwater currents, installation of groins at strategic locations along the shoreline may be necessary. If the bottom is scoured so extensively that the stability of the structure is endangered, an underwater groin consisting of very heavy rubble may be effective in deflecting the underwater current. In such an installation, the groin is designed to accumulate waterborne material so that the floor around the foot of the structure builds up and serves as a stabilizing influence.

Rubble-mound breakwaters, jetties, and seawalls occasionally are repaired by adding crushed stone to the crowns and seaward slopes and grouting the new surfaces. Repairs of this type, which must be made in stages because of tides, must produce a 3-foot or greater protective layer of grouted stone. Figure 10-3 illustrates the general scheme of repairs.

When concrete armor units are required for repairs, complete physical characteristics may be found in reference 10.

Future Inspection Requirements: Where continued erosion is experienced, increased inspection may be required in order to prevent massive loss of rubble mound structure materials.

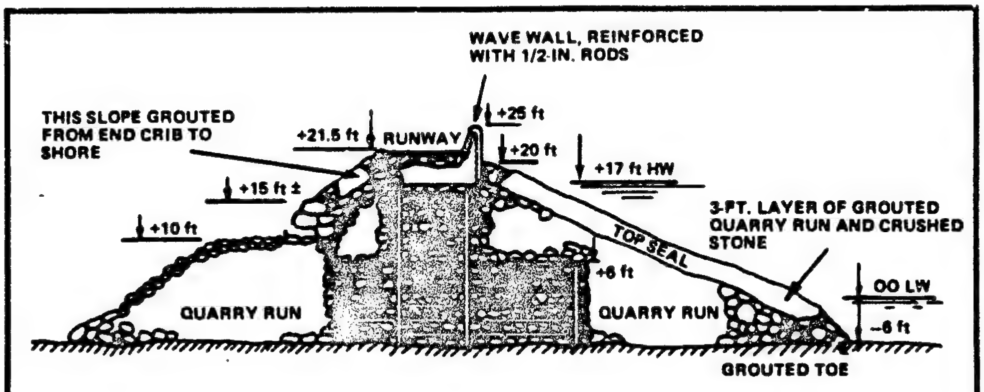


Figure 10-3. Repair of Breakwater with Grout Layer.

EARTH-FILLED STRUCTURE REPAIR

Problem: Erosion or settlement has occurred. Any breaching of or impairment to an earth structure exposed to moving water sharply increases its susceptibility to damage. For this reason it is very critical that any required maintenance be identified and carried out as quickly as possible.

Description of Repairs: Repairs to these structures will consist of replacement of lost or subsided soil and measures to prevent further loss or settlement.

a. **Replacement of Soil.** Where there is evidence of erosion or loss of soil, protective coverings, such as rockfill or armor units, should be removed and the internal fill material inspected. Any necessary repairs in the form of replacement of properly compacted soil should be made, and the protective slope covering replaced in a manner to ensure no further erosion. A series of soil layers of varying coarseness may be used to ensure that the finer, central materials cannot be washed out through the coarser, shell materials. In some cases, it may be economical to protect the side slopes with asphaltic concrete, soil cement, or even reinforced portland cement concrete. In cases where the side slopes are exposed only to atmospheric erosion, vegetation such as ice plant or grasses may be adequate.

b. **Types of Compaction.** The type of compaction selected should be based upon the soil type. Vibratory compaction is more efficient with granular soils, whereas kneading types of equipment, such as sheepsfoot rollers, are more applicable to cohesive soils. Vibratory rubber-tired compactors in the 12- to 15-ton range are reasonably effective for all types of soil. Soil lifts should generally be limited to layers having a compacted thickness of no more than 6 inches, except where it has been demonstrated that the compactors are capable of achieving the required densities throughout the full depth of thicker lifts. Such a situation might exist with a vibratory compactor on relatively clean, cohesionless material. For backfilling sheet pile cofferdams or other structures with limited space, it may be necessary to use small hand-operated tampers or compactors. The importance of compaction generally increases with decrease in grain size of the soil.

c. **Compaction Control.** The performance of soil embankments improves with density, so fill materials should generally be placed at as high a density as is economically feasible, particularly with the finer-grained soils. There is a particular moisture content for a particular soil at which the maximum density is obtained under a specific compaction effort. Therefore, moisture control is an important factor in efficient compaction techniques, particularly with silts, clays, and mixed soils.

The two most common standards for compaction control are the standard Procter (ASTM D 698) and the modified Procter (ASTM D 1557) tests. The latter method represents a larger compactive effort than the former and has been adopted to account for the higher compactive capability of construction equipment. However, the standard considered most pertinent for waterfront structures is still the standard Procter. This is because the lower compactive effort results in a slightly higher optimum moisture content for maximum density, and the higher moisture content is more compatible with the expected in-service conditions of waterfront structures.

A typical requirement for many waterfront structures is to specify a compacted density of 95 percent of standard Procter, but this may vary with the type of structure and its present condition. It is generally desirable to place a soil material in a structure in as close to its long-term stable condition as possible. Although clean, granular materials should be placed in as saturated a condition as is practicable, fine-grained or mix-grained soils may require moisture contents to be maintained within a particular optimum range. Often, control of water content with respect to the optimum value is left up to the contractor, since he can elect to replace rigorous moisture control with increased compactive effort. Where excess compactive effort could result in damage to the structure, such as in quaywalls or cofferdams, the compactive effort should be minimized and the moisture content controlled as well as is practicable. For these latter types of structures, it is also very important that design densities not be exceeded. Excessive compaction might result in undesirable lateral stresses in structural members.

d. **Dewatering.** Where excavation and replacement of soil takes place below the water table, it may be necessary to dewater the site by use of seepage barriers, such as sheet piles. Where soil permeabilities are greater than 1×10^{3} fpm, subsurface drainage by well points or deep wells may be necessary. Prior to planning dewatering procedures, it is necessary to determine permeability and piezometric levels by field observations. The major concern is to avoid instability through piping or heaving by controlling the upward hydraulic gradient at the base of the excavation. Hydraulic gradients (head loss per unit length of flowpath) of one lead to immediate instability in all cases, but exit gradients of 0.5 to 0.75 will cause unstable working conditions even in clean sands. Silty materials are even more critical.

e. **Preventing Loss or Settlement of Soil.** Maintaining good surface drainage is the most important preventive maintenance measure for earthwork structures. Efficient runoff of rainfall and overflow water must be ensured. If subsurface drainage features exist, they

must be kept clear; for example, periodic cleaning of weep holes. Hand placed riprap can be added to the slope just behind the sheet piling, if storm runoff results in heavy soil loss.

After a settlement problem occurs, measures to seal the structure, and fill voids, may be necessary. The following paragraphs describe two methods:

(1) **Sealing.** The loss of soil from behind quaywalls, or from within sheet pile cofferdams, requires sealing of the structure to prevent further loss of material prior to replacement of suitable backfill. Coarser-grained materials are preferred where available, since they are less subject to leaching or erosion. Fine-grained materials are desirable only where very low permeability is required, such as in the core of an earth dam. When fines are used, construction of inverted filters or sealing of structural joints are necessary to prevent erosion. Where materials consist of the very erodable silts or fine sands, the structure must be sealed to prevent influx of surface water.

(2) **Grouting.** In some cases, it may be more expedient to either seal or repair a damaged structure by injecting grout. Grout may be used to reduce the permeability of the soil fill or its foundation and, thereby, minimize erosion or leaching. It may also be used to physically strengthen the structure to make it better able to resist wave or ship loadings, and superimposed dead loads.

Cavities or voids in the soil structure may be grouted using sand/water mixtures, portland cement, clay, chemical grouts, or a combination of these materials. Sand/water mixtures are applicable where large cavities are present and the paths of soil loss have been sealed off. Cement grout is not applicable if the effective grain size of the in-place soils, D (the sieve size through which only 10 percent of the soil would pass), is less than 0.5 mm for loose soils and 1.4 mm for dense soils. Portland cement grout is most applicable where the grout can be pumped directly into cavities.

An effective grouting procedure for sandy materials consists of injecting solutions of sodium silicate and calcium chloride. This procedure both solidifies and impermeabilizes the soil, but it is extremely expensive. Mixtures of cement and clay are also used, sometimes with the addition of a chemical deflocculent.

EARTH-FILLED STRUCTURE REPAIR (Continued)

One of the more recently developed chemical grouts polymerizes in the soil voids; however, it is also expensive. With fine-grained backfills, grouting is generally of no benefit except to fill cavities or to seal off paths of soil removal.

Future Inspection Requirements: Where the rate of erosion or settlement has been increasing, or where a major problem has been encountered and corrected, increased inspection may be necessary to ensure that the repair is effective.

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APPENDIX A

SPECIFICATIONS AND STANDARDS

Number	Document Title
	WOOD AND TIMBER
FED SPEC TT-P-19	Paint, Latex (Acrylic Emulsion, Exterior Wood and Masonry)
FED SPEC TT-P-102	Paint, Oil, Alkyd Modified, Exterior, White and Tints
FED SPEC TT-E-490	Enamel, Silicone Alkyd Copolymer, Semigloss (For Exterior and interior) Non-Residential
FED SPEC TT-W-571	Wood Preservation: Treating Practice
MIL SPEC MIL-P-28582	Primer Coating, Exterior Lead Pigment-Free (Undercoat for Wood, Ready Mixed, White and Tints)
NFGS-02361	Round Timber Piles (Fresh Water and Land Use Only)
NFGS-02483	Wood Marine Piling
NFGS-02491	Pier Timber Work
ALSC	Lumber Standards
ASTM D 25	Round Timber Piles
AWPA C1, C3	Preservative Treatment, Pressure Process
AWPA M4	Standard for the Care of Pressure-Treated Wood Products
AWPB MP-1/MP-2/MP-4	Water-Borne Preservatives and Creosote Treatment for Marine Pilings
AWPB MLP	Standard for Softwood Lumber, Timber, and Plywood Pressure Treated for Marine (Saltwater) Exposure
SSPC SP-1	Solvent Cleaning
	CONCRETE
FED SPEC TT-P-95	Paint, Rubber: For Swimming Pools and other Concrete and Masonry Surfaces

APPENDIX A (Continued)

SPECIFICATIONS AND STANDARDS

Number	Document Title
	CONCRETE (Continued)
FED SPEC TT-S-230	Sealing Compound: Elastomeric Type, Single Component (For Caulking, Sealing, and Glazing in Buildings and other Structures)
FED SPEC TT-C-555	Coating, Textured (For Interior and Exterior Masonry Surfaces)
MIL SPEC MIL-P-24441	Paint, Epoxy-Polyamide, Exterior Top coat, Dark Gray, Formula 155-RO - 6 Type 1
MIL SPEC MIL-C-83286	Coating, Urethane, Aliphatic Isocyanate, for Aerospace Applications
NFGS-02363	Cast-in-Place Concrete Piling, Steel Casing
NFGS-02367	Prestressed Concrete Piling
NFGS-03300	Cast-in-Place Concrete
ACI 211	Selecting Proportions for Normal, Heavyweight, and Mass Concrete
ACI 212	Admixtures for Concrete
ACI 318 Series	Building Code Requirements for Reinforced Concrete
ACI 515	Use of Waterproofing, Damp-proofing, Protective, and Decorative Barrier Systems
ACI 503R.1/2/3/4	Use of Epoxy Compounds with Concrete
ASTM A 615	Deformed and Plain Billet Steel Bars for Concrete Reinforcement
ASTM A 616	Rail Steel Deformed and Plain Bars for Concrete Reinforcement
ASTM A 617	Axle-Steel Deformed and Plain Bars for Concrete Reinforcement
ASTM A 775	Epoxy-Coated Reinforcing Steel Bars
ASTM C 33	Concrete Aggregates Specification

APPENDIX A (Continued)

SPECIFICATIONS AND STANDARDS

Number	Document Title
	CONCRETE (Continued)
ASTM C 150	Portland Cement Specification
ASTM C 260	Air-Entraining Admixtures for Concrete
ASTM C 494	Chemical Admixtures for Concrete
ASTM C 881	Epoxy-Resin-Base Bonding Systems for Concrete
	STEEL
FED SPEC TT-P-645	Primer, Paint, Zinc Chromate, Alkyd Type
FED SPEC VV-P-236	Petrolatum, Technical
MIL SPEC MIL-C-18480	Coating Compound, Bituminous, Solvent, Coal-Tar Base
MIL-STD-889	Dissimilar Metals
ASTM A 36	Structural Steel Specification
ASTM A 242	High-Strength Low-Alloy Structural Steel
ASTM A 572	High-Strength Low-Alloy Columbium-Vanadium Steels of Structural Quality
ASTM A 588	High-Strength Low-Alloy Structural Steel 50 KSI minimum yield Point to 4 in. thick
ASTM A 690	High-Strength Low-Alloy Steel H-Piles and Sheet Piling for use in Marine Environments
SSPC SP-5/SP-6/SP-10	Commercial Blast Cleaning
SSPC Paint No. 16	Coal-Tar Epoxy-Polyamide, Black, (or dark Red) Paint

APPENDIX A (Continued)

SPECIFICATIONS AND STANDARDS

Number	Document Title
	SOIL
ASTM D 698	Moisture-Density Test; standard Procter
ASTM D 1557	Moisture-Density Test; modified Procter

ACI - American Concrete Institute
ALSC - American Lumber Standards Committee
ASTM - American Society for Testing and Materials
AWPA - American Wood Preservers Association
AWPB - American Wood Preservers Bureau
NFGS - NAVFAC Guide Specification
SSPC - Steel Structures Painting Council

GLOSSARY

Alligatoring	Intersecting cracks and ridges in weathered coatings that give an appearance of an alligator hide.
Anode	The consumable component (electrode) of cathodic protection systems and corrosion cells.
Apron	That portion of a wharf or pier carried on piles beyond solid fill.
As-built drawings	Drawings that show all deviations from the original design and changes made during construction.
Ashlar	Sawed or dressed square stones used in facing masonry walls.
Bench mark	A mark on fixed and enduring object indicating a particular elevation. It is used as a reference in topographic surveys, tidal observations, and construction.
Bent	Framework crosswise to the length of a structure (e.g., trestle, bridge, or pier) which it supports; usually designed to support stringers.
Berth	The water area at the edge of a wharf or pier reserved for a vessel.
Bitt	A single- or double-posted steel fitting on a deck of a ship or pier to which mooring lines are secured.
Bollard	A single- or double-posted steel fitting on a pier or wharf around which mooring lines from vessels are tied.
Breakwater	A substantial structure, located at the outer limits of a harbor or anchorage, to protect the inner waters against the effects of heavy seas.
Breast board	A temporary barrier or retaining board used to prevent the face of an excavation caving in.
Brow	A portable walk or bridge between ship and pier, or landing platform for use of personnel while the ship is berthed. It is usually equipped with handrails and has rollers on the shore end.
Bulkhead	A retaining wall to prevent sliding of earth or fill into water.
Bullrail	A guard, usually wooden, located along the outer edge of a wharf or pier to prevent accidental loss of equipment into the water.

Buoy	A float moored to the bottom to mark the position of shoal, channel, or anchorage limit, or a floating component of a ship mooring.
Caisson	(1) A support foundation (dam) formed by pouring concrete, driving sheet lock piling, or forming other material into a hollow box or cylinder; allows maintenance and repair work to be done below water level. (2) A controlled submergence floating hull used as a watertight entrance closure for a graving dock.
Camel	A floating device acting as a fender and used to separate a moored vessel from a pier, wharf, quay, or other vessel.
Cap	(1) A horizontal timber secured to the top of a row of piles. (2) A fitted or threaded piece to protect the top of a pile from damage while being driven.
Capstan	A rotating spindle-mounted drum on which cable or rope is wound for raising anchors or other heavy weights.
Cathodic protection	An electrical method of preventing metal corrosion in a conducting medium by placing a charge on the item through a transformer or a sacrificial anode.
Chock	(1) A wedge or block, commonly wooden, fitted between piling or other structures to steady them. (2) A metal casting with two horn-shaped arms curving inward between which mooring lines may pass; used for passage, guiding, or steadying of mooring or towing lines.
Cleat	A metal fitting on the deck of a pier or ship usually with two projecting horns around which a rope may be made fast (as by belaying it).
Cobblestone	A naturally rounded stone.
Cofferdam	A temporary watertight enclosure from which water is pumped to expose normally immersed areas.
Cold iron	Capability or service supplied to a docked ship so that necessary utilities (e.g., steam, water, electricity, sewage removal, telephones) are provided from shore rather than from the power plant on the ship.
Concrete armor unit	See dolos, tetrapod, and tribar.
Cradle	A platform with keel and bilge blocks for holding ships.
Curb	See bullrail.

GLOSSARY (Continued)

Deadman	A block or other heavy item, usually of concrete, buried in the ground to which is attached a steel rod or cable for anchoring objects.
Deck	The working surface of a wharf, pier, or vessel.
Dock	The water area adjacent to a wharf or pier to which a ship can be secured.
Dolos	A concrete armor unit used for riprap.
Dolphin	A structure usually consisting of a cluster of timber piles. It is placed at the outward end of piers and wharves, or along shore, to guide vessels into their moorings, to fend vessels away from structures, shoals, or the shore, or to support navigation aids.
Dolomite	Limestone or marble rich in magnesium carbonate.
Drydock	A facility for exposing the normally underwater portion of a ship for construction, inspection, repair, or hull maintenance.
Elastomer	An elastic rubberlike substance (such as a synthetic rubber or a plastic having some of the physical properties of natural rubber).
Electrolyte	A nonmetallic medium capable of conducting electricity by the movement of ions rather than electrons.
Electro-osmosis	The movement of a conducting liquid (such as water in clay) through a porous diaphragm under the action of an electromotive force applied to electrodes on opposite sides of the diaphragm.
Estuary	A water passage where the tide meets a river current, especially an arm of the sea at the lower end of a river.
Fender	A device, usually of wood, rubber, or rope to prevent damage to a vessel or shore facility by impact or abrasion.
Filter blanket	A layer or progressively graded series of soil layers, or plastic cloth filter woven of synthetic fibers, separating material of different grain size. The separation prevents the fine soil from entering into the open spaces of the coarser one.

Fire curtain wall (fire stop)	A transverse wall under a pier which extends from the underwise of the decking to low water to contain a fire. (Each side of wood or metal fire curtain wall is protected by automatic sprinklers or deck openings for use of revolving water nozzles.)
Fish plate	A steel plate that laps a joint or an area of a piling reduced by corrosion. It is secured to the sides so as to connect the members end to end or to strengthen them.
Float	A floating platform used for disembarking from a boat or working around waterfront structures.
Floating drydock	A ship or U-shaped structure in cross section that can be submerged by flooding to permit a vessel to enter and then be dewatered to raise the vessel supported on keel and bilge blocks out of the water.
Fouling	An accumulation of deposits, especially marine biological growth.
Gad	A pointed iron or steel bar for loosening rock.
Gravity wall	A massive structure that obtains stability through its own weight.
Graving dock	A fixed basin of usually either stone masonry, reinforced concrete, or sheet piling cells near the water's edge. It can be closed off from the waterway by a movable watertight barrier, usually a floating caisson.
Groin	A narrow structure projecting out, usually close to right angles, from the shoreline. It is designed to influence offshore currents and wave action in a manner that will minimize erosion of the shoreline.
Holiday	A small hole in a coated surface arising from imperfect application.
Hyphal threads	A filament outgrowth of fungus.
Incise	To make cuts into wood parallel to the grain to permit the take up of greater quantities of preservative.
Jetty	A structure (such as a mound or wall) at or near the entrance to a harbor or river constructed to confine the flow of water due to currents and tides, and to maintain the entrance free of sandbars.
Leaching	The process of extracting the soluble components from a material by percolation.

Littoral drift	Movement of sediment by underwater currents and tidal action, usually resulting in formation of sandbars.
Marine railway	An inclined groundway extending into the water, with a mobile cradle that moves on the groundway tracks, for hauling a ship out of or into the water.
Marine borer	Destructive organism in seawaters that attacks untreated or poorly treated wood; especially active in warm waters.
Mill scale	Oxide layer formed on iron and steel when heated for rolling, forging, or other processing.
Mole	A rubble-mound structure that extends outward from shore into the navigable water of a harbor. Generally, the level top is appreciable in area and contains paved roads, railroads, and crane trackage.
Mound	An artificial embankment or ridge composed of sand, gravel, and cobbles and constructed on the ocean floor by dumping the material from scows and barges.
Pier	An open- or closed-type structure usually extending perpendicularly from the shore into sheltered navigable water, designed for berthing, loading or unloading cargo, repair, fueling, and general servicing of vessels. It normally provides berthing space on both sides for its entire length.
Piezometer	An instrument for measuring pressure or compressibility.
Pile (piling)	A long, slender timber, steel, or reinforced concrete structural element driven, jetted, or otherwise embedded into the ground to support a vertical load, to resist a lateral force, or to resist water or earth pressure.
Potable	Suitable for drinking.
Preservative	A material with the property of retarding deterioration.
Quarrystone	A diamond or square cut stone.
Quay	See wharf.
Quaywall	A heavy structure fronting on navigable water, and parallel to the shore, behind which earth fill is placed. Its function is to act as a bulkhead as well as to provide for berthing of vessels or other service.

Radiography	The process of making a picture upon a sensitive surface by a form of radiation other than light. It is used for detecting flaws in welds and other metal structures.
Relieving platform	A platform built on piling or other support structures to carry fill to support surface structure.
Revetment	A stone or concrete facing to sustain an embankment.
Rubble	Rough and uncut stones, irregularly shaped and of various sizes ranging up to 1,000 cu ft each and up to 90 tons each.
Riprap	Stones, boulders, or concrete armor units of miscellaneous size placed without order on the surface of an earthen structure or embankment to act as protection against erosion.
Seasoning check or crack	A lengthwise separation of a wooden timber that extends across the rings of annual growth and commonly results from stresses set up in the wood during seasoning.
Seawall	A massive gravity-type structure built along, and generally parallel to, the shoreline; designed to protect the shore against erosion resulting from wave action.
Sheepsfoot roller	A rolier with spikes inserted to compact, perforate, or scarify the rolled surface.
Shoal	A submerged elevation rising from the bed of a shallow body of water covered by unconsolidated materials and may be exposed at low water.
Shoreline	The boundary area where water meets land.
Shotcrete	Shotcrete or gunite is a concrete that is pneumatically placed in layers usually from 1 to 2 inches. Water is mechanically added to the dry mixture at the nozzle, which shoots the freshly mixed concrete (really a mortar) at the surface prepared for its reception.
Stanchion	An upright bar, post or support usually on a ship.
Stringer	A horizontal framing member used to support a floor or deck.
Syntactic foam	A foam composed of hollow spheres in a resin matrix.
Tetrapod	A nonreinforced concrete armor unit used for riprap.
Traprock	Fine-grained igneous rock.

GLOSSARY (Continued)

Tremie	A steel tube 12 inches or greater in diameter used for depositing concrete underwater, having at its upper end a hopper for filling.
Tribar	A reinforced concrete armor unit used for riprap.
Tsunami	Large seawaves caused by seaquakes or volcanic eruptions.
Tuck-point	To finish the joints between masonry units with a narrow ridge (bead) of mortar. Pointing mortars usually shrink after placement and if finished flush with the masonry units will result in a concave joint.
Turning basin	An enlarged space at the end of a canal or narrow channel to permit vessels to turn around.
Ultrasonic testing	High frequency sound readings to determine voids in landfills and flaws in welds, etc.
Vertical lift	A platform which is lowered into the water to receive a small vessel and then elevated out of the water by hoisting equipment.
Wale	A long, horizontal structural member of timber or steel used for bracing vertical members. Also known as "waler" or "ranger."
Weep hole	An opening in a retaining wall, canal lining foundation, or other structure to drain away accumulated water.
Wharf	An open-type marginal platform structure, usually parallel to the shoreline, that is used primarily for berthing of vessels. It is usually connected to the shore at more than one point but may also have continuous access along the shore. It ordinarily provides berthing along the outboard face.

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